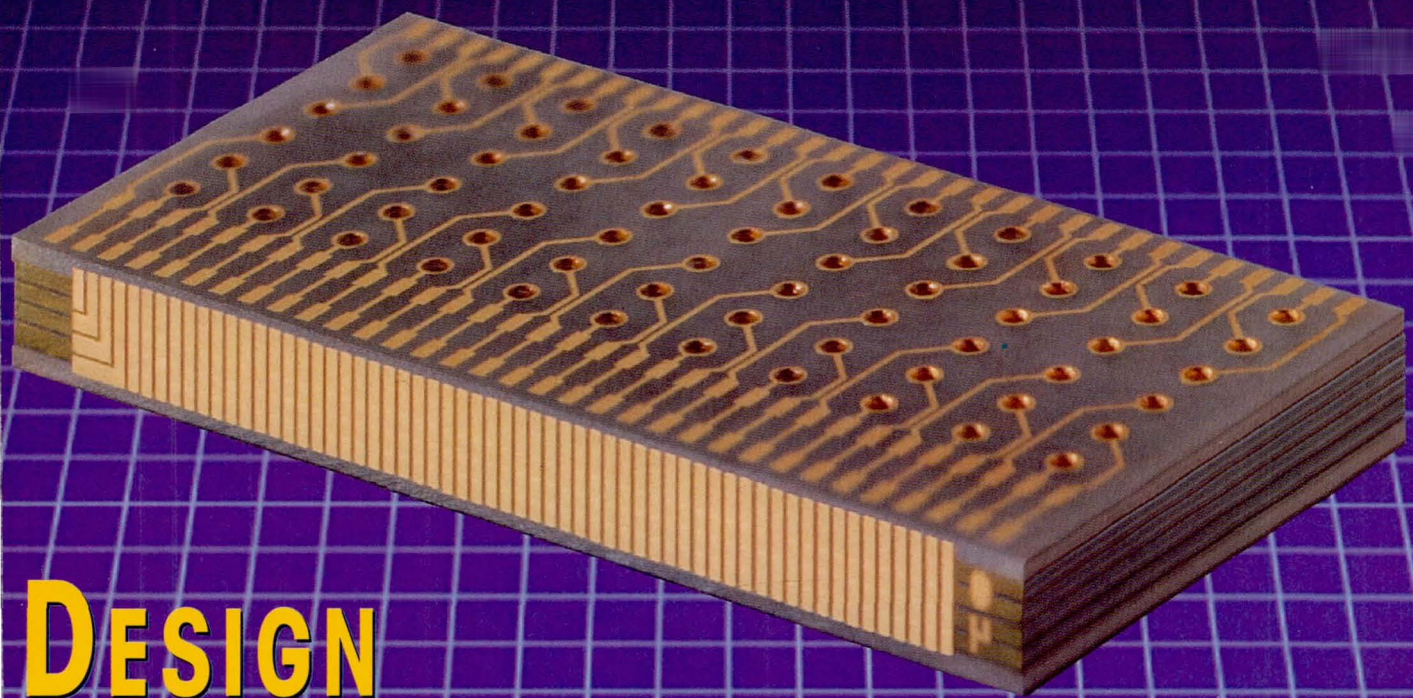
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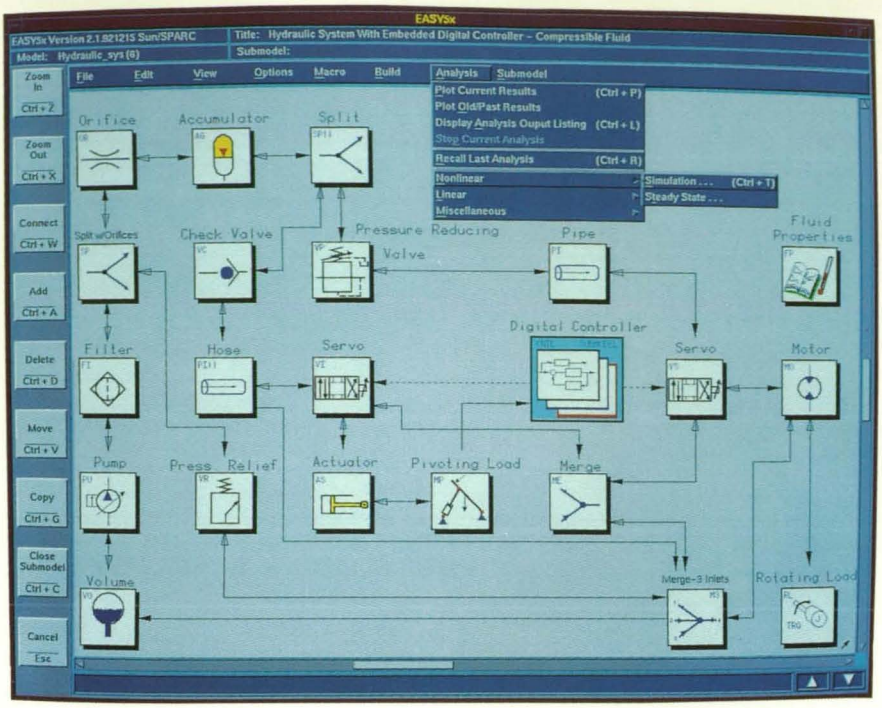
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Design Breakthrough

3D Chip Stacking Saves Space, Packs More Memory



Modeling and analysis completed with a Motif®-based X Window™ interface.

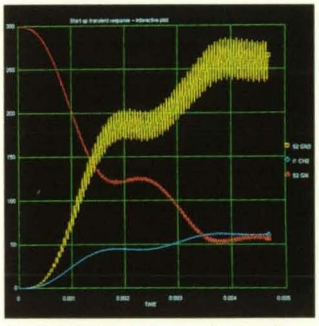
Is it a pipe dream?

Do you have enough power? What happens if a line breaks? And, can you control it?

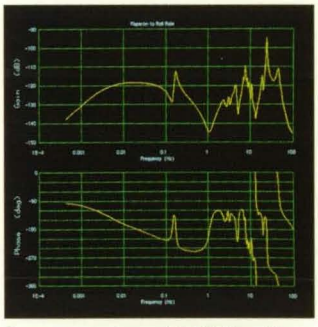
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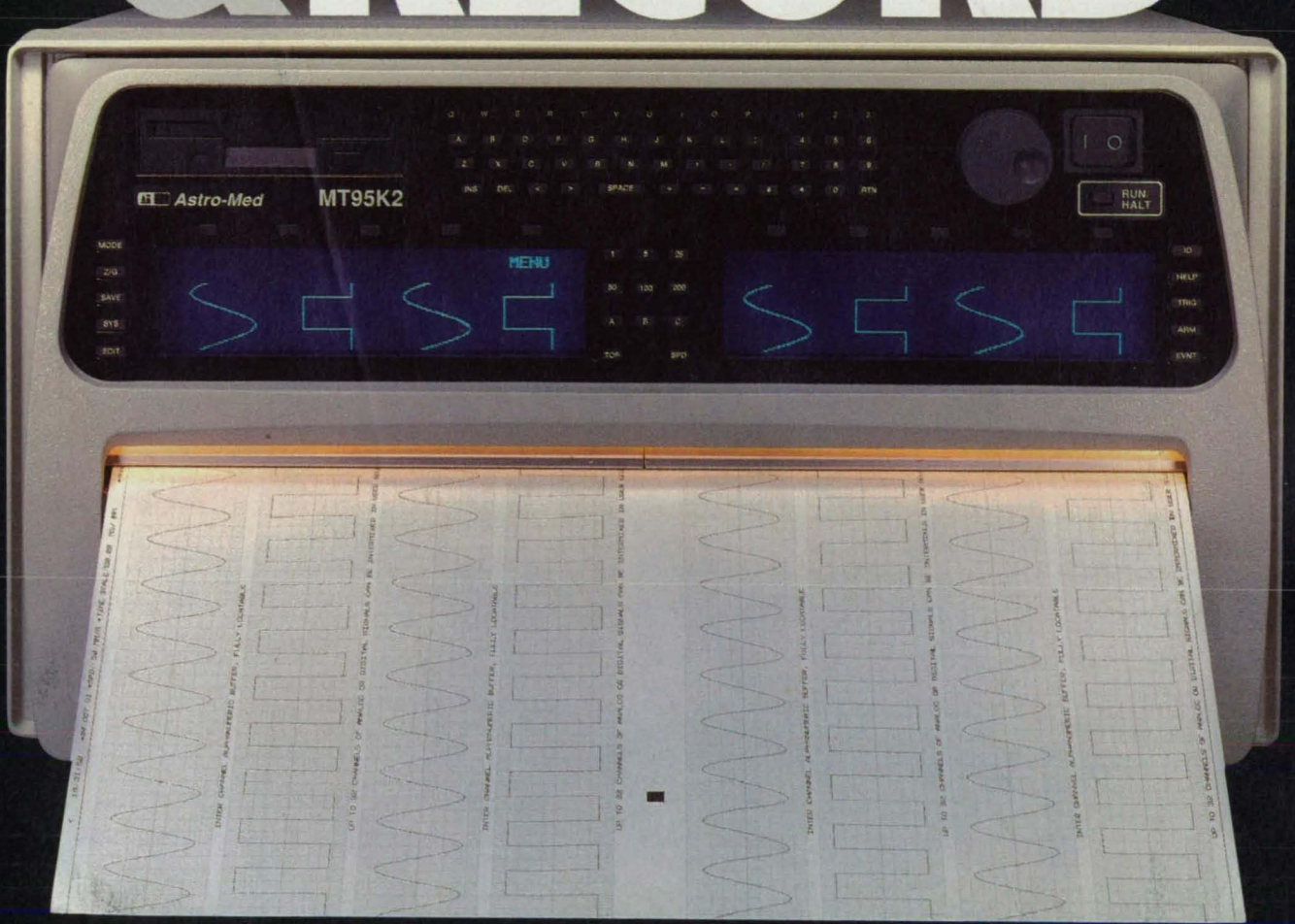
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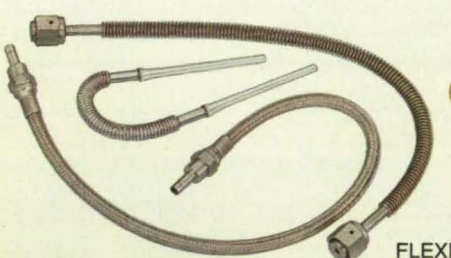
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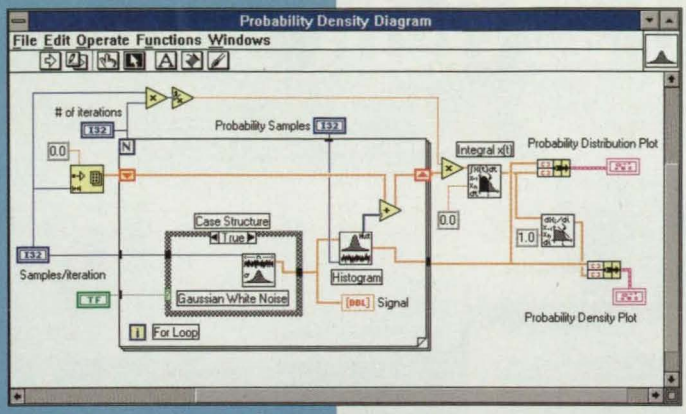
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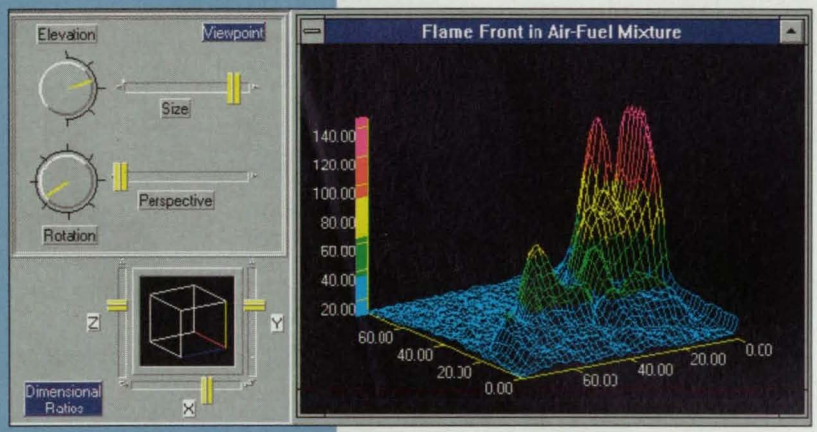
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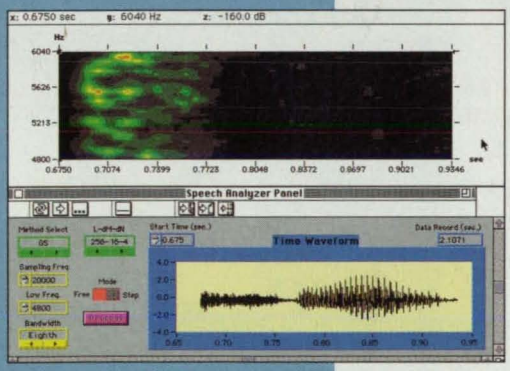
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Surface plot of a flame front using LabVIEW and the SurfaceView toolkit.

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Gabor Spectrogram
National Instruments

The Gabor Spectrogram displays a portion of the sentence "I take two people out for breakfast," computed and displayed with LabVIEW.

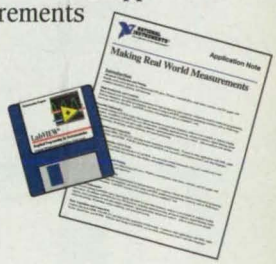
Data courtesy of NIH.

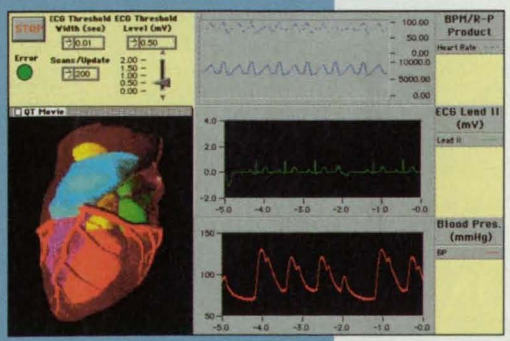
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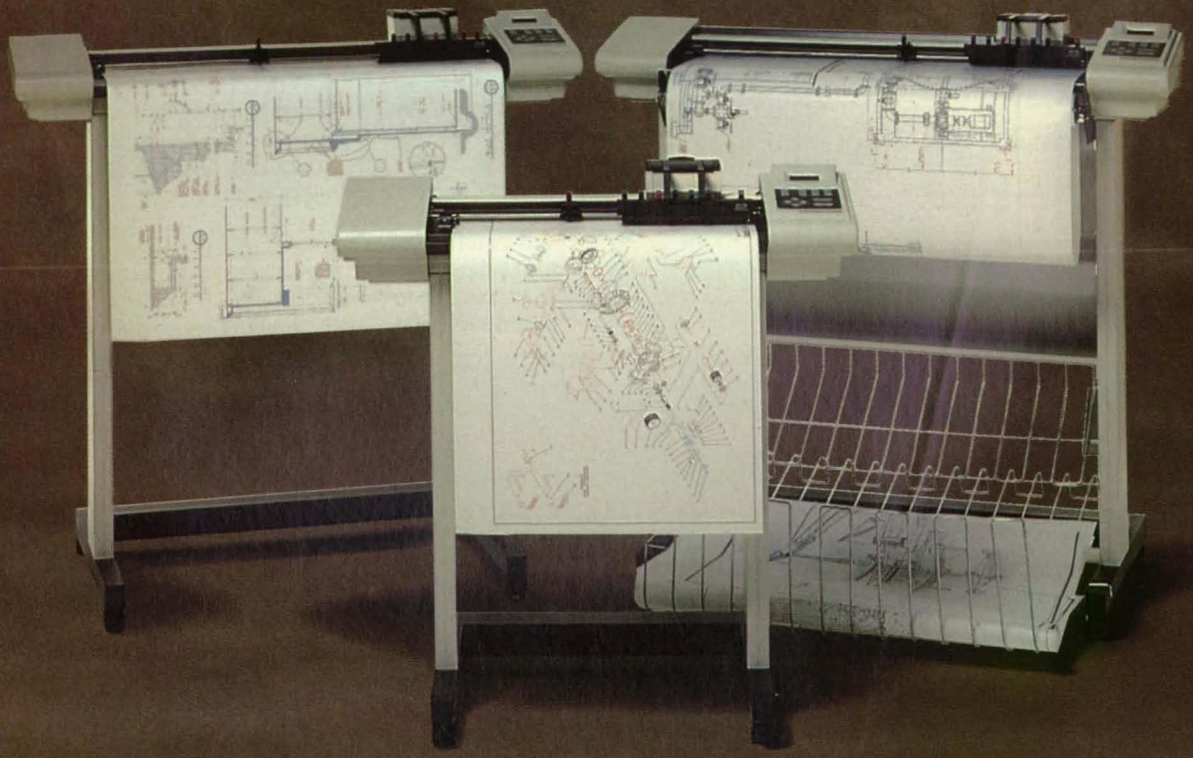
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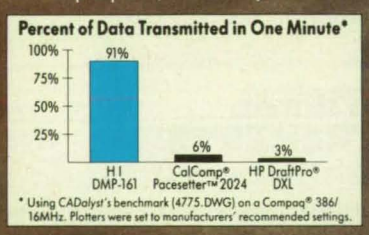
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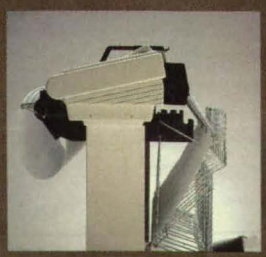


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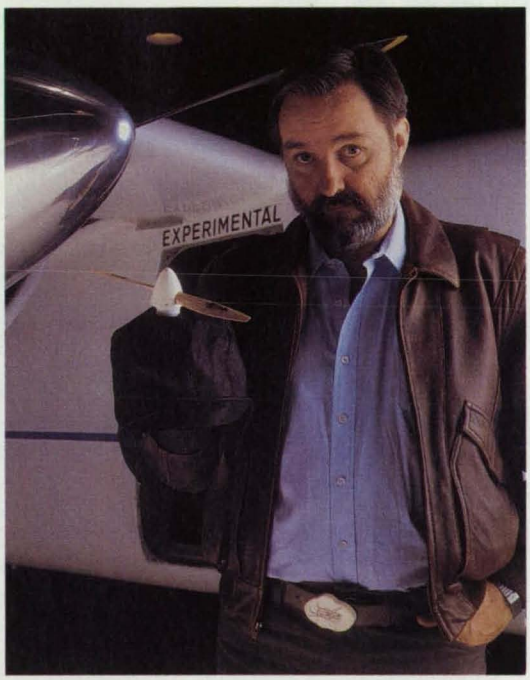
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Why ONE OF AMERICA'S MOST THOUGHT-PROVOKING ENGINEERS NOW USES THE DESIGN TOOL THAT THINKS.

Two years after the Voyager completed its record-shattering around-the-world flight, you could still find its designer, Burt Rutan, working at a drafting table with pencil and paper.

Hardware wasn't the problem. He had computers. His company could buy any design system worth owning. What kept Burt grounded was software. CAD so clumsy, it squashed creativity. Or so weak, it simply couldn't do his job.

Maybe that's why the first time he sat down to design with Ashlar Vellum, Burt compared the exhilaration to flight. Vellum is the first CAD program with a built-in autopilot.



Burt Rutan. Inventor. Engineer. Another Vellum user with no intention of going back to the drawing board.

INDUSTRIAL-STRENGTH CAD THAT THINKS.

From GD&T symbols to NURB splines to DXF and IGES file format translators, Vellum has every professional design and drafting tool your job demands. But its real breakthrough is an expert system called The Drafting Assistant™ (Pat. Pending)—built-in intelligence that instantly makes every designer more productive. Even on enormously complex jobs.

Instead of fighting the keyboard, or guessing about alignment, Vellum pinpoints and spells out every logical design point for you, right on the screen.

Draw a simple line and the midpoints, endpoints, and construction lines appear automatically. Click the mouse and you get precise alignment to 16 decimal places, in a fraction of a second.

THE POWER OF PARAMETRICS.

Before Vellum, using CAD for conceptual design was like trying to draw in the dirt with a backhoe.

Now, Vellum makes precise design as natural as free hand sketching, with the combined power of Parametrics and Associative Dimensioning.

Simply draw a rough approximation of your design, dimension it, plug in values and *click*: geometry is automatically redrawn to scale. A part needs to change? Simple. Just change the dimensions and the geometry updates as you watch. Or change the geometry and all the dimensions update perfectly.

FROM CONCEPT TO FINISH IN HALF THE TIME.

According to Burt, "the only way to fully appreciate Vellum is to sit down and use it; tackle a tough job, right off."

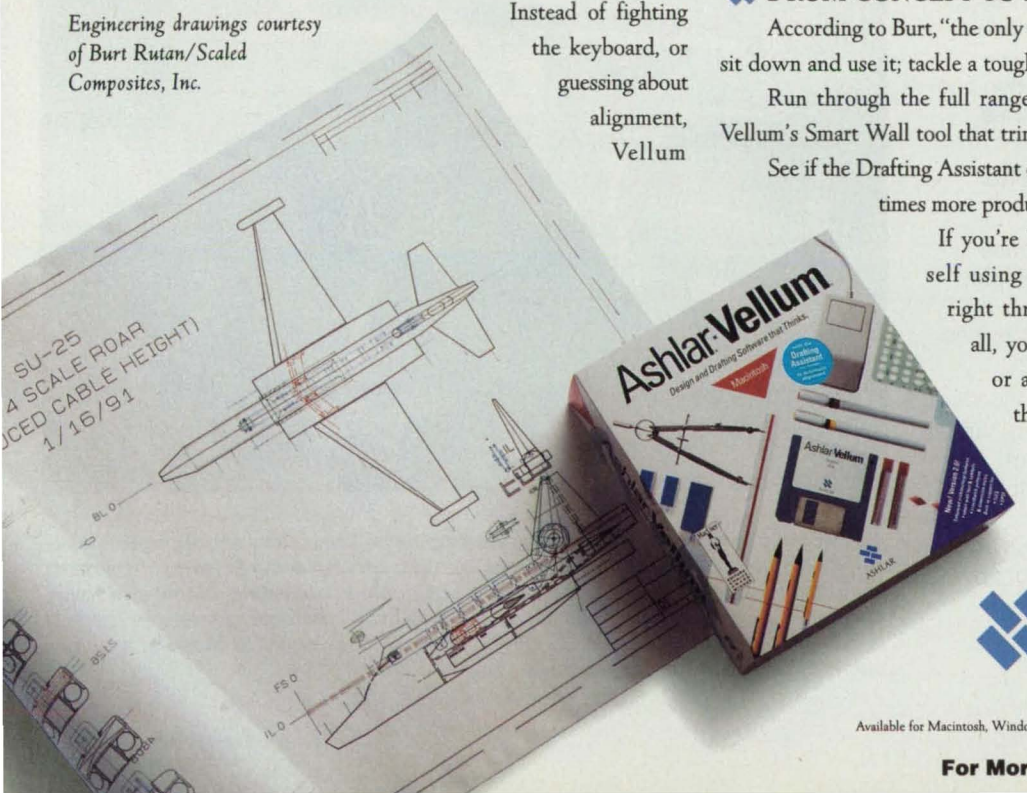
Run through the full range of professional CAD tools. Try Vellum's Smart Wall tool that trims walls automatically.

See if the Drafting Assistant doesn't make you two, or even three times more productive than any other CAD package.

If you're like Burt Rutan, you'll find yourself using Vellum from conceptual design right through finished drawings. Best of all, you'll never give the drafting board, or another CAD program, a second thought.

For more information, a free video, a trial version, or the name of an authorized Ashlar reseller near you call (800) 877-ASHLAR.

Engineering drawings courtesy of Burt Rutan/Scaled Composites, Inc.



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May 1993
Volume 17 Number 5

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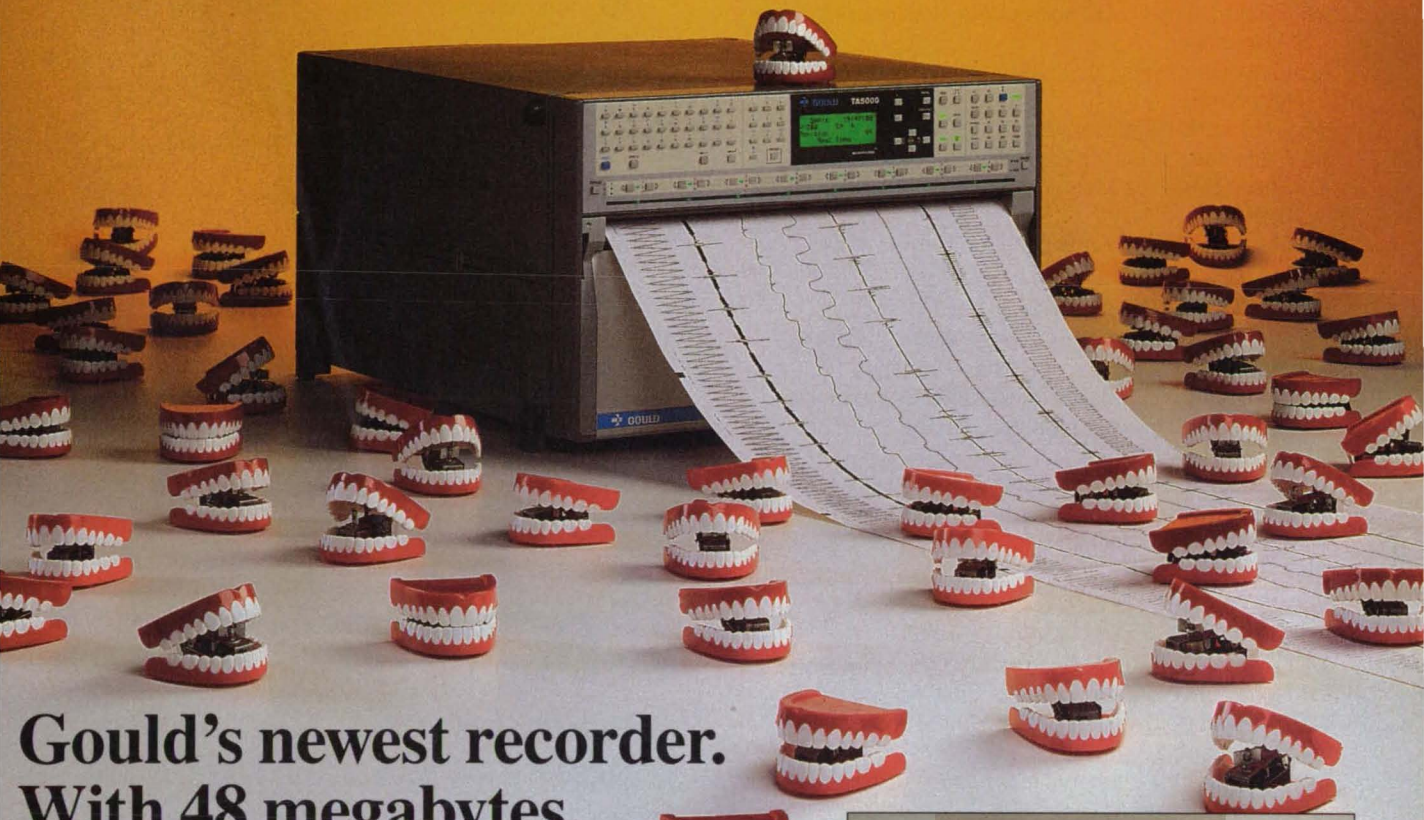
(Continued on page 8)



Photo courtesy Jet Propulsion Laboratory

A telerobotic system assembled at the Jet Propulsion Laboratory performs such tasks as picking up tools, removing a thermal blanket, and replacing screws. The system comprises a satellite simulator, a camera-positioning subsystem, a dual-arm robot, and a control room that contains force-reflecting hand controllers for teleoperation. It is being used to develop telerobotic-repair capabilities equal to those of a human operator. See the tech brief on page 43.

GOULD
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Gould's newest recorder. With 48 megabytes.

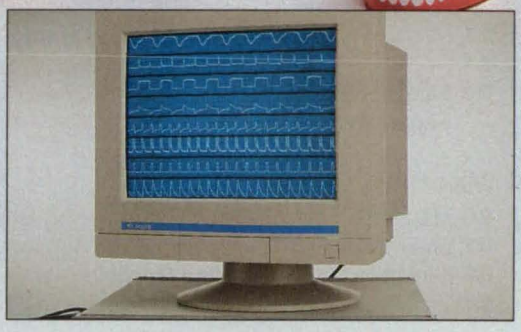
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NTB 5/93

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on the cover:

The Memory Short Stack™ from Irvine Sensors Corp. contains up to ten memory chips, bonded and interconnected, and occupies the same space as a single conventional integrated circuit. Serving as a "virtual memory chip," the configuration yields faster processing speeds, higher levels of integration, increased reliability, lower power requirements, and, by eliminating packaging, reduces manufacturing costs. Licensed to IBM Corp., the technology was developed with the aid of NASA and the Department of Defense. Turn to Mission Accomplished, page 14.

Photo courtesy Irvine Sensors Corporation

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Pioneer 10, which was built to last 21 months in space, is celebrating its 20th year. Over the past two decades, the success of NASA's mission to Jupiter has rested heavily on two key instruments: an imaging photopolarimeter (IPP) and an infrared radiometer. Both sensors were developed and built by Hughes Aircraft Company. The IPP, which initially provided spectacular color pictures of Jupiter, is now being used as a sun sensor, because of its ability to focus on small, distant objects. At 5 billion miles from Earth, Pioneer 10's 570-pound probe is the most distant man-made object in space.

Managing masses of information on global, environmental change — a major goal of NASA's Earth Observing System (EOS) — is one of the world's most formidable information management system challenges. The Hughes solution for the EOS Data and Information System (EOSDIS) will electronically interconnect NASA and other government agencies with researchers worldwide — facilitating research collaboration through a distributed federation of heterogeneous computer systems. Historically, global change data has been awkward to access, tough to translate and difficult to distribute. However, with EOSDIS, scientists in faraway places can easily work closely together, analyzing our fragile planet and recommending ways to preserve its environment and natural resources.

GM's prototype electric car, called Impact, will have Hughes-built electronics powering the motor and controlling the recharging. This all solid-state system requires no scheduled maintenance and will appear in the showrooms well ahead of the 1998 date when California will require auto manufacturers to begin selling zero pollution cars. Recharge points will be installed at buyers' homes and will also appear in other locations, including employee parking lots, downtown parking facilities, malls, and restaurants. With its Hughes-built "Inverter," the Impact will be a model for cars that help protect our environment.

Thirty remote silver and copper mines in Peru will now have the same access to high-quality telecommunications as companies in urban areas thanks to a Hughes satellite network. The comprehensive voice and data network provides communications between the sites via Hughes' Very Small Aperture Terminals. Previously they were linked only by UHF radio. This will be a boon to Peruvian mining companies, which can now interface their onsite computers directly with computing facilities in the nation's capital, Lima, maintaining a live operational database at all times.

Hughes is now producing the world's first interactive entertainment simulators, which offer the excitement of a true simulation environment through integrated real-time control of vision, motion, and CD quality sound. These simulators use many of the same technologies Hughes developed for sophisticated flight simulators used in training pilots of Boeing 747-400s and military aircraft. The Commander simulator capsules are hydraulically operated as you steer through the computer image-generated screen experience. Because the graphics are generated as the adventure is experienced, you can go wherever you want in the scenario. The Commander includes a variety of safety features and will be located at arcades, shopping malls, bowling alleys, leisure centers, amusement/theme parks, as well as airports and museums.

For more information write to: P.O. Box 80032, Los Angeles, CA 90080-0032

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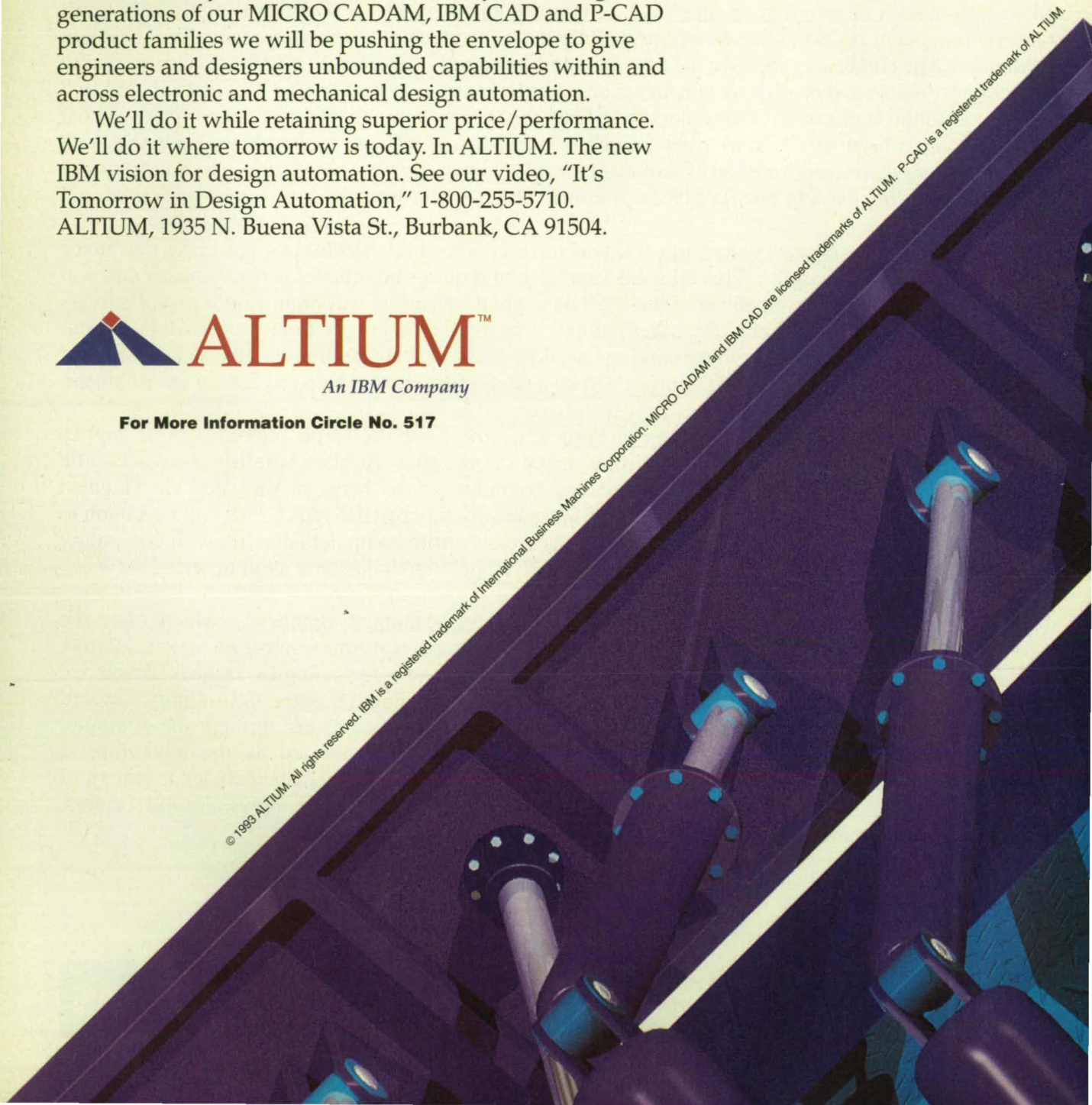
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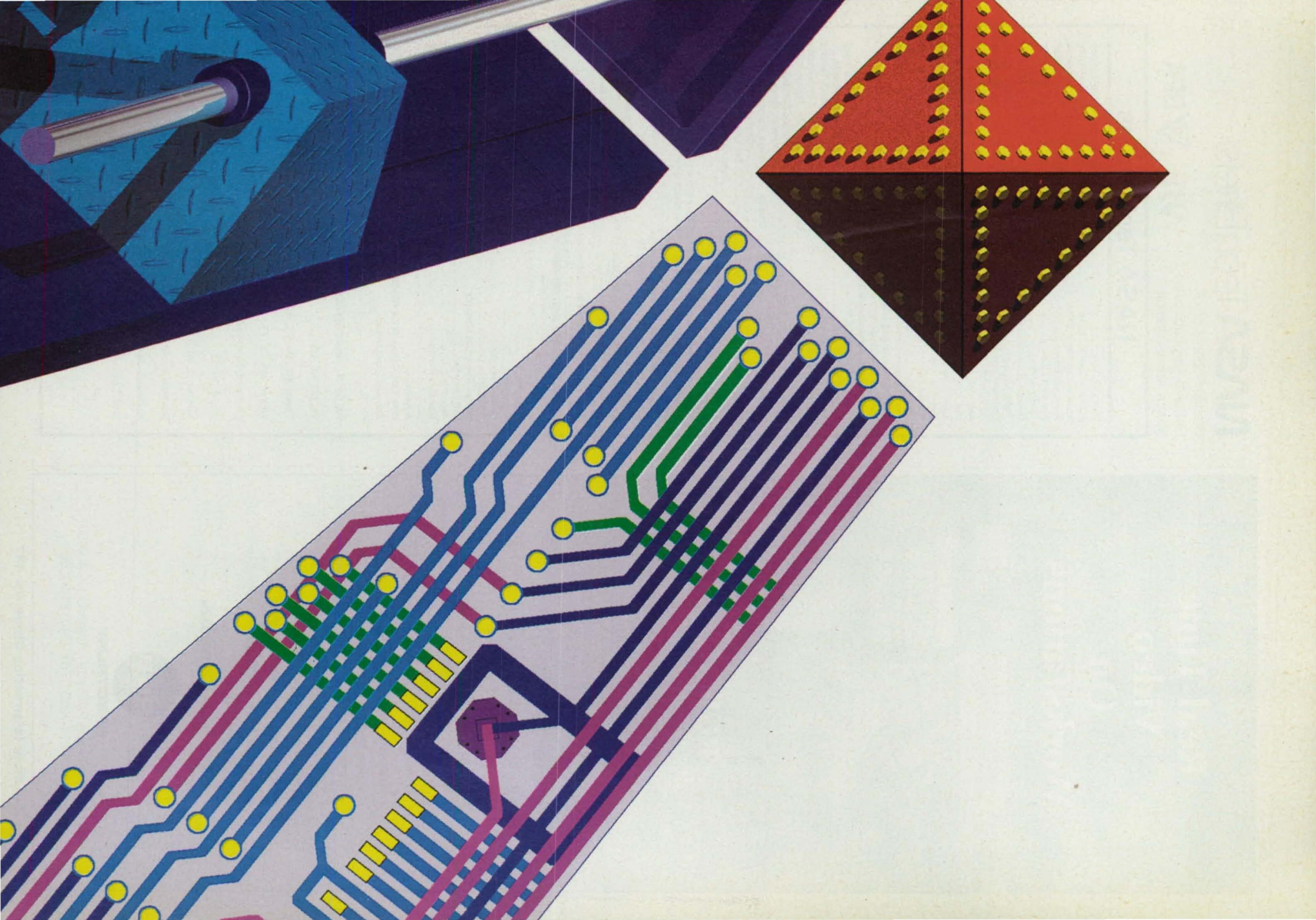
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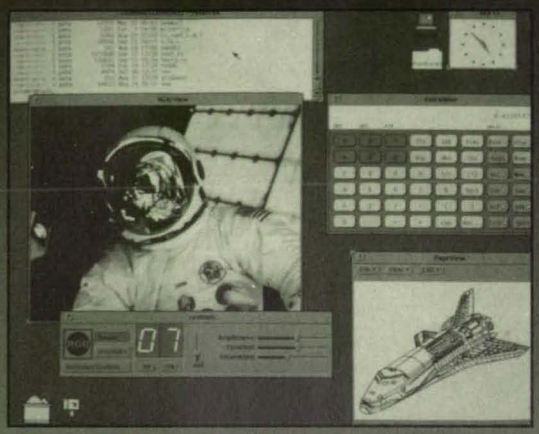
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Briefs & Supporting Literature:
Provided to National Aeronautics and Space Administration by
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NASA Tech Briefs are provided by the National Aeronautics and Space Administration, Technology Transfer Division, Washington, DC:
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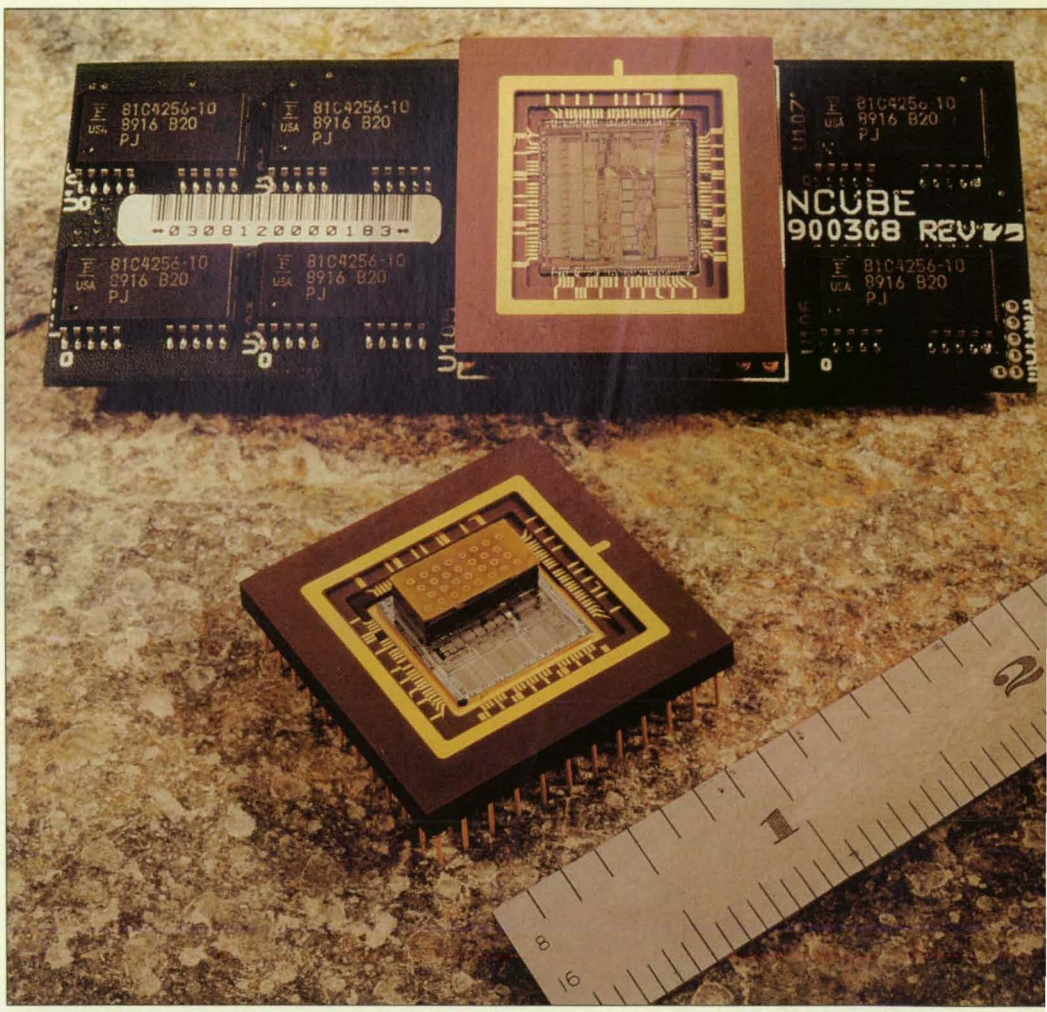
Stacking integrated circuits into a 3D structure, a technology pioneered by Irvine Sensors Corp. of Costa Mesa, CA, provides an elegant solution to the data processing bottleneck that results from the distances between chips on a circuit board. Irvine Sensors' innovative chip-stacking technique, developed with the aid of NASA and the Department of Defense, offers faster processing speeds, higher levels of integration, and lower power requirements than conventional chip sets.

Also called "cubing," the process promises such applications as a parallel processing module the size of a dictation tape cassette that could reduce dramatically the size and weight of memory-intensive instruments, for example, medical imaging devices. Irvine Sensors already has engineered a stack the size of a sugar cube to replace a PC's main circuit board.

The stacking technique assembles integrated circuits thinned to as little as 0.2 mm and extremely thin layers of laminate. The configuration significantly increases density and thermal conductivity while improving reliability by eliminating most of the interconnect junctions such as wire bonds, TAB pads, and bump bonds. Putting the chips closer to one another shortens the signal line, thereby reducing the signal line capacitance and minimizing I/O drive currents. Eliminating several levels of packaging reduces manufacturing costs.

Last June, the 40-employee company entered into a joint venture with IBM Corp. to refine and commercialize the technology. To facilitate high-volume, cost-competitive manufacturing of the stacks, IBM has established a Cubing Process Development Center in Burlington, VT. IBM's initial focus was on "full stacks," in which as many as a hundred chips are mounted like a loaf of bread in a half-inch-high cube.

Two months after the agreement was signed, Irvine Sensors introduced independently the first commercial version of the 3D Memory Short Stack™, a 4-megabit 512K x 8 SRAM package measuring just 7.1 mm x 13.7 mm and 1.5 mm high—about the size of a single conventional integrated circuit. Short stacks contain up to ten chips mounted like a stack of pancakes for use in applications with limited "head room" such as in telecommunications electronics. The success of the short stacks, which offer the same performance benefits as the full stacks, prompted the



Innovative chip-stacking technology from Irvine Sensors Corp. dramatically reduces memory footprint and offers such performance benefits as faster processing speeds and lower power requirements. In the foreground above is a processor incorporating a chip stack that contains ten 4-megabit DRAMs. The stack replaces the ten DRAMs on the processor board in the background.

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expansion of the IBM agreement to include them.

Irvine Sensors plans to release numerous short stack products in packaged and unpackaged form that will permit a variety of interconnect techniques to be used in next-level assembly. The unpackaged stacks will target designers now using hybrid multichip modules and chip-on-board packaging techniques.

The company will pursue a broad range of markets, according to John Carson, Irvine Sensors' chief scientist and senior vice president. "The IBM project is 100 percent commercial, but we can qualify the products for space and military applications," he said. The company also has signed development contracts with other mainframe companies such as Unisys.

Carson, an infrared imaging specialist, describes the technology's evolution as a "14-year odyssey" that resulted in 28 patents and $35 million in development costs. Irvine Sensors began operations in 1980, working for the Defense Advanced Research Projects Agency (DARPA) on a method to bring analog signal processing technology as close as possible to the focal plane of electro-optical surveillance systems. The project sought to speed signal processing and reduce interference while conserving space and weight.

In 1985, Irvine Sensors began to explore employing the 3D stacking technology as a more efficient alternative to existing planar integrated circuit packaging. Further DARPA development funding yielded a prototype full stack that in turn garnered the attention of NASA and the Strategic Defense Initiative Organization, which share the need for extremely dense memories in a small payload.

Problems with space-borne electromechanical recorders prompted researchers at NASA's Goddard Space Flight Center to seek a better, nonmoving data storage technology, according to Dan Dalton, head of the center's Flight Data Systems Branch, and led to a Small Business Innovation Research (SBIR) grant for Irvine Sensors. "We wanted a solid-state recorder with a big memory capacity—Irvine's chip stacks offer the highest unit silicon density available," he explained.

"The Goddard SBIR helped bring the technology to the point where it could be useful for commercial purposes," said Carson. The project recently was completed with delivery of short stacks to Goddard for space qualification.

Irvine Sensors has received eight Phase I and five Phase II SBIRs from NASA, including an ongoing project at the Jet Propulsion Laboratory's Advanced Flight Computing Laboratory to evaluate the chip-stacking technology for space missions. The lab assesses the electrical, thermal, and functional characteristics of new and advanced technologies.

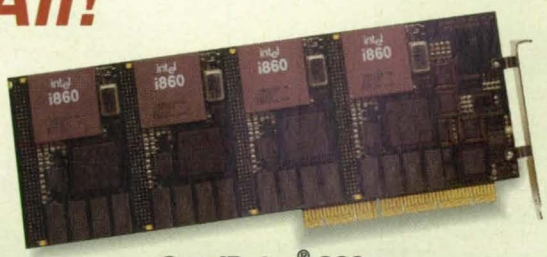
"The chip stacks have the potential to enable a variety of microspacecraft and microrover technologies," said Leon Alkalaj, supervisor of the lab's Flight Computer Development Group. "We also are investigating dual-use applications in which the characteristics—mass, power, and volume—that make the stack attractive for space use also will benefit ground computing technologies such as laptops and supercomputers." ❑

For more information about the technology described in this article, contact Myles F. Suer or Lynn G. O'Mara, Irvine Sensors Corp., 3001 Redhill Avenue, Building III, Costa Mesa, CA 92626, Tel. 714-549-8211.

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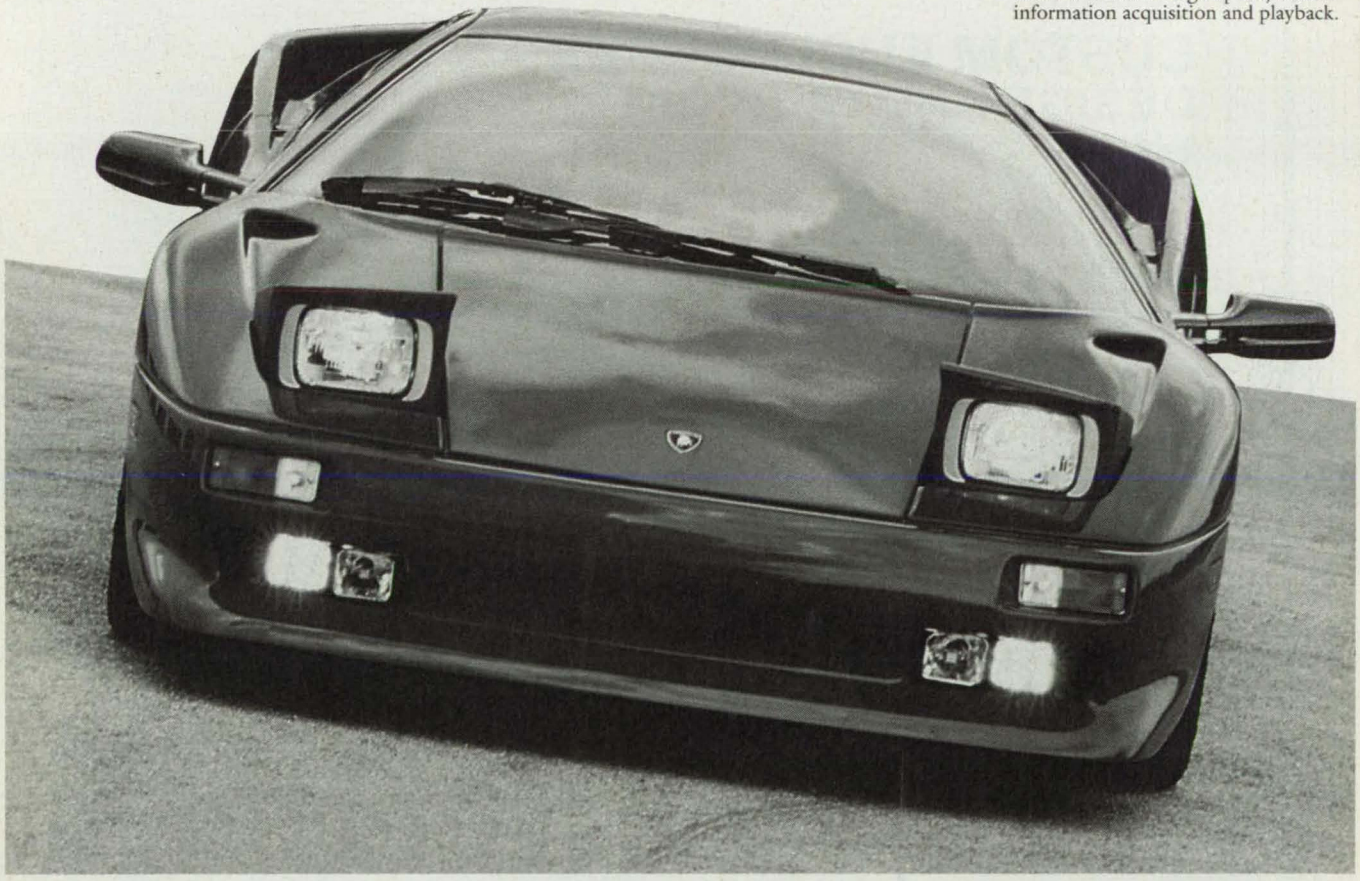
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New Product Ideas

New Product Ideas are just a few of the many innovations described in this issue of *NASA Tech Briefs* and having promising commercial applications. Each is discussed further on the referenced page in the appropriate section in this issue. If you are interested in developing a product from these or other NASA innovations, you can receive further technical information by requesting the TSP referenced at the end of the full-length article or by writing the Technology Utilization Office of the sponsoring NASA center (see page 20). NASA's patent-licensing program to encourage commercial development is described on page 20.

Self-Amplified Optical Pattern Recognizer

These recognizers are being developed for use in recognition of patterns, in optical computing, and in optoelectronic neural networks. The apparatus is said to be "self-amplified" because the signal is amplified within a diffraction-grating filter to many orders of magnitude greater than in prior optical pattern recognizers.
(See page 56.)

Films Containing Optically Nonlinear Diacetylene Monomer

Optical properties of these films can be tailored to a particular application by choice of the concentration of monomer and thickness. Uniform films with thicknesses of a few micrometers could serve as optical waveguides.
(See page 62.)

Magnetostrictive Roller-Drive Stepping Motor

A proposed motor would provide stepped angular motion with angular increments of the order of 100 microradians. It would be particularly suitable for precise, high-torque, fail-safe-braking, direct drive of a robot joint, without the bulk and weight of an additional brake mechanism and gear train.
(See page 86.)

Polyimides Made From 4,4'-Isophthaloyldiphthalic Anhydride

Long-term thermo-oxidative stabilities of these materials were found to be excellent at 300 °C and 350 °C in air. These materials, which have controlled levels of crystallinity and excellent resistance to chemicals at high temperatures, are valuable additions to the polyimide family of coatings and films.
(See page 24.)

Molecular-Weight-Controlled, End-Capped Polybenzimidazoles

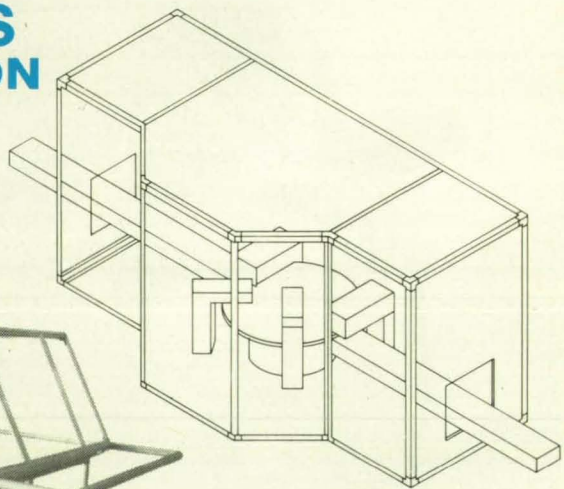
Compared to commercial polybenzimidazole, these polymers exhibit improved solubility in polar aprotic solvents and better compression moldability. Poly(arylene ether benzimidazole)s have potential applications as adhesives, coatings, films, fibers, membranes, moldings, and composite matrix resins.
(See page 22.)

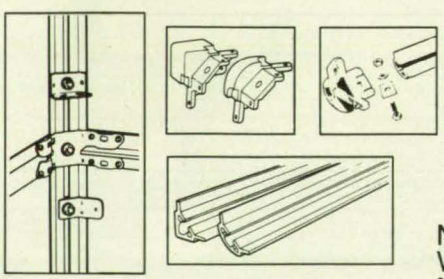
Enzymatic Catalytic Beds for Oxidation of Alcohols

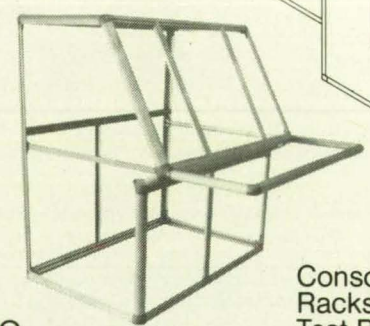
An integrated reactor module contains both an alcohol-oxidizing catalytic bed and an oxygen saturator. It performs better than a catalytic bed placed downstream of a separate oxygen-saturator module.
(See page 64.)

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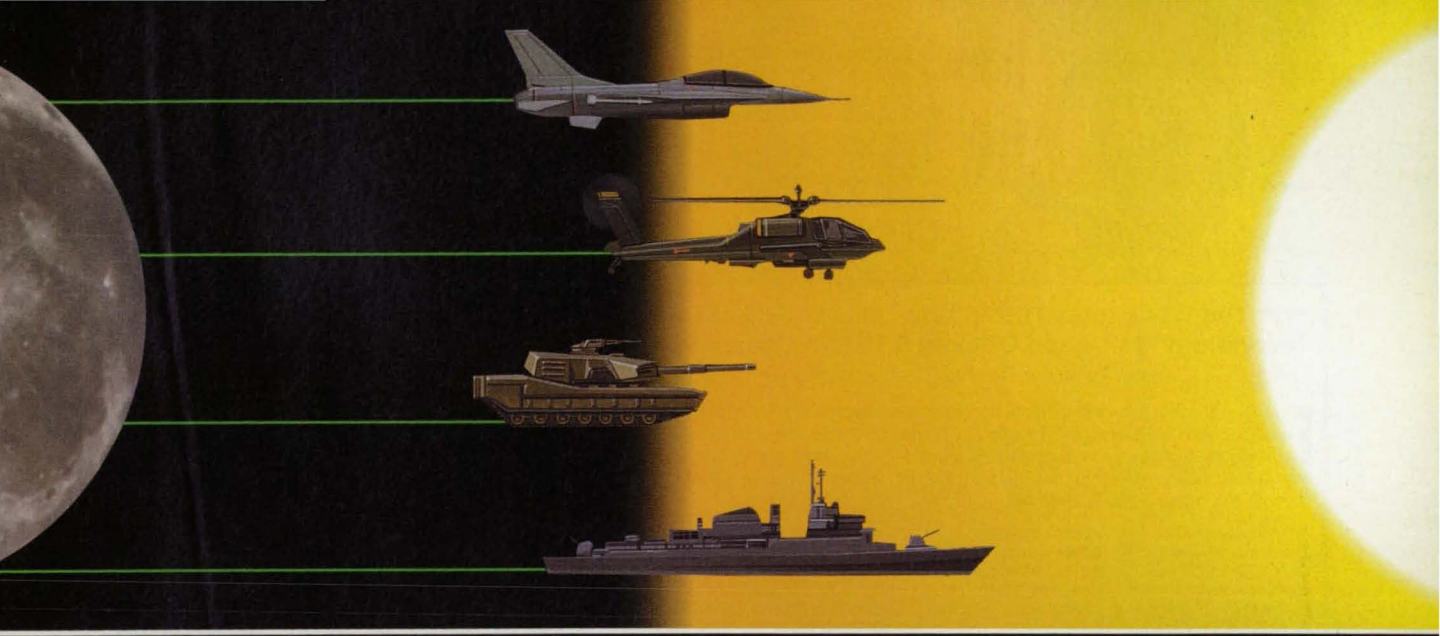


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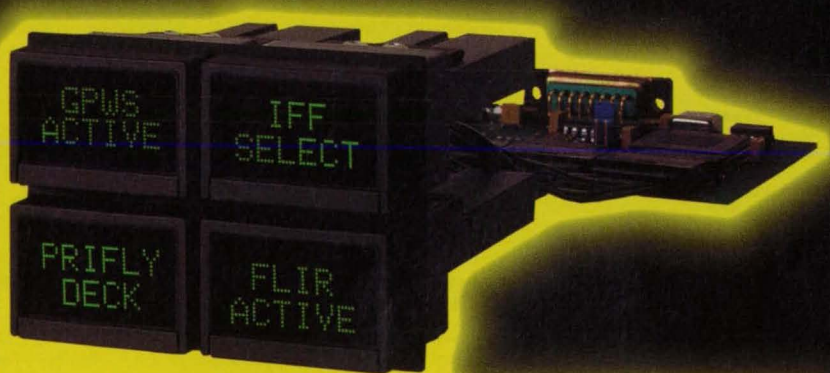
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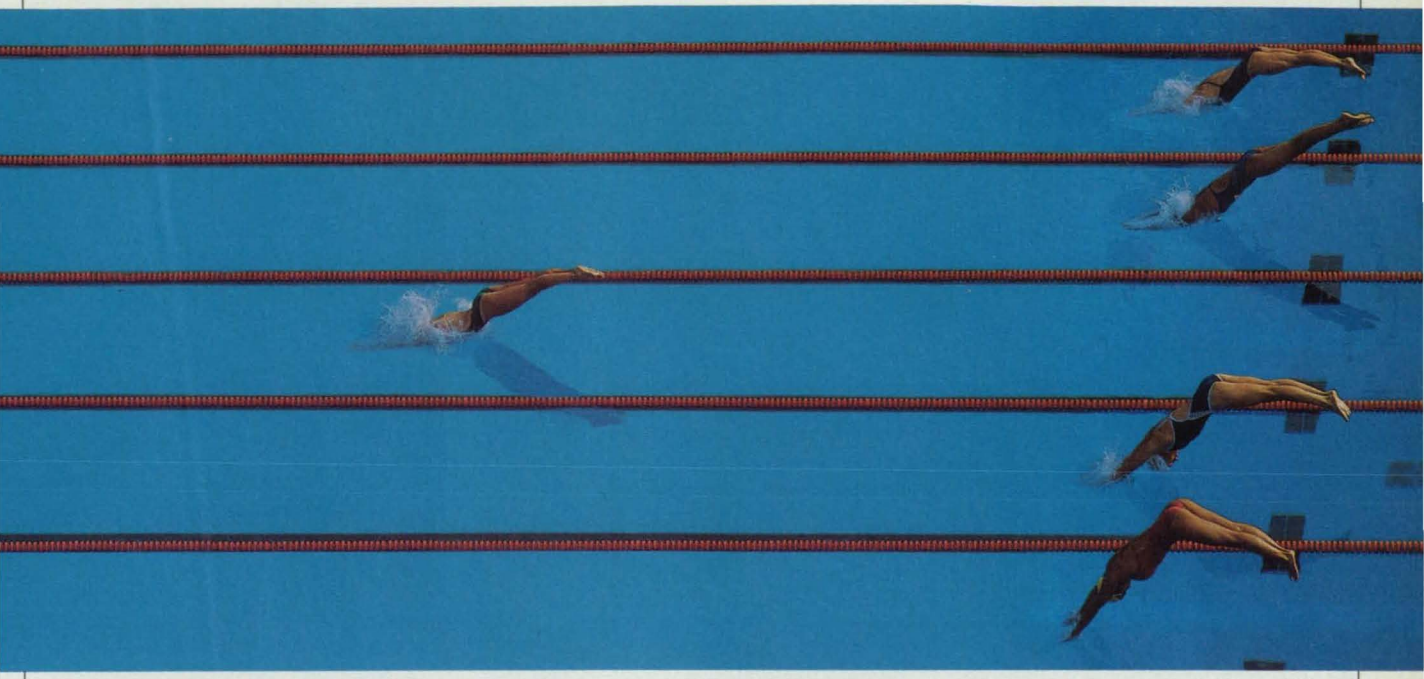
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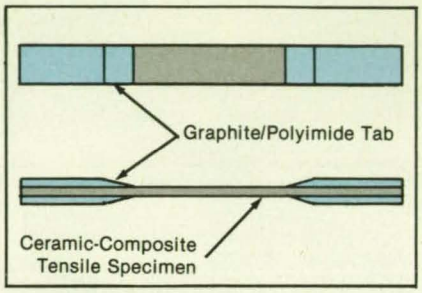
Graphite/Polyimide Tabs for High-Temperature Tensile Tests

Delamination from ceramic composite specimens is prevented.

Lewis Research Center, Cleveland, Ohio

Tabs made from a composite of graphite and PMR-15 polyimide enable the high-temperature tensile testing of flat coupons (see figure) of ceramic-matrix composites. Tabs made of the graphite/PMR-15 composite could also be used in the high-temperature tensile testing of flat coupons of ceramics, metals, and metal-matrix composites.

Heretofore, the high-temperature tensile testing of ceramic-composite specimens has involved the use of metal tabs. However, the significant difference between the coefficients of thermal expansion of the specimens and of the tabs resulted in delamination between the specimens and the tabs. The metal tabs are glued to the specimens with a commercial epoxy-based structural film adhesive. The tabs have to be held at a temperature of 177 °C (351 °F) to cure this adhesive. Upon cooling, the residual stresses caused by differential thermal shrinkage cause failure of the adhesive joints. In contrast, tabs made of graphite/PMR-15 are sufficiently compliant to prevent delamination.



Graphite/PMR-15 Tabs enable the high-temperature tensile testing of specimens of ceramic-matrix composites.

The specimens are 200 mm (8 in.) long and 13 mm (0.5 in.) wide. The middle, or gauge, section of the specimen can be held at a temperature up to 1,550 °C (2,820 °F) in air; the regions of the specimen near the tabs must be limited to 230 °C (450 °F) to prevent failure of the adhesive. The tabs offer adequate shear strength without degradation to enable high-temperature tensile testing of reaction-bonded silicon nitride reinforced with unidirectional silicon fibers.

This work was done by John Z. Gyekenyesi and Demetrios S. Papadopoulos of **Lewis Research Center**. *No further documentation is available. LEW-15342*

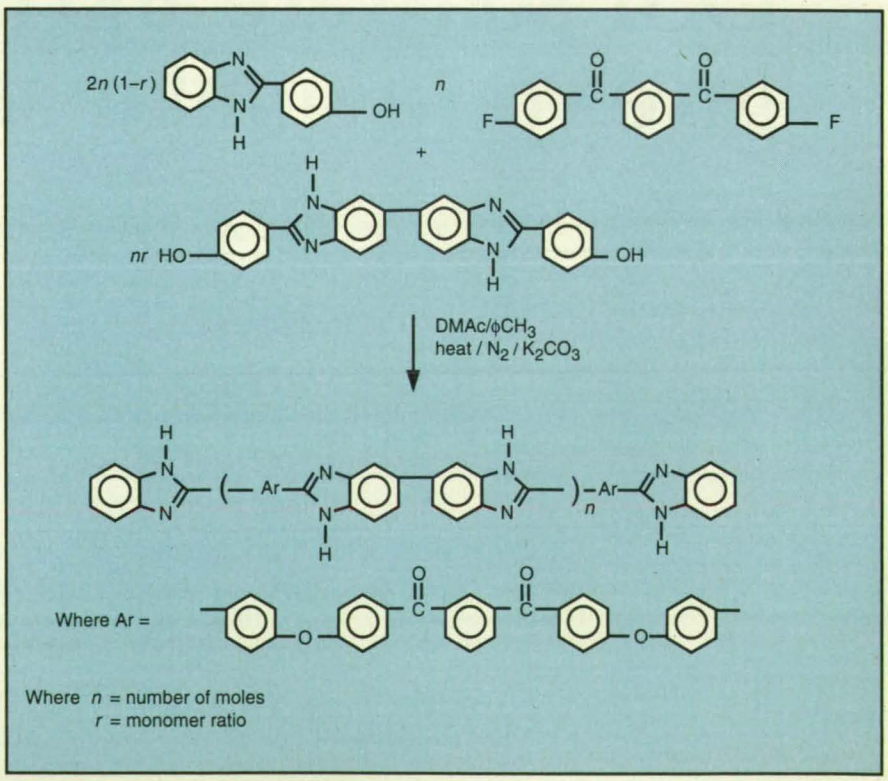
Molecular-Weight-Controlled, End-Capped Polybenzimidazoles

Prepared by aromatic nucleophilic displacement, these polymers exhibit favorable physical and mechanical properties.

Langley Research Center, Hampton, Virginia

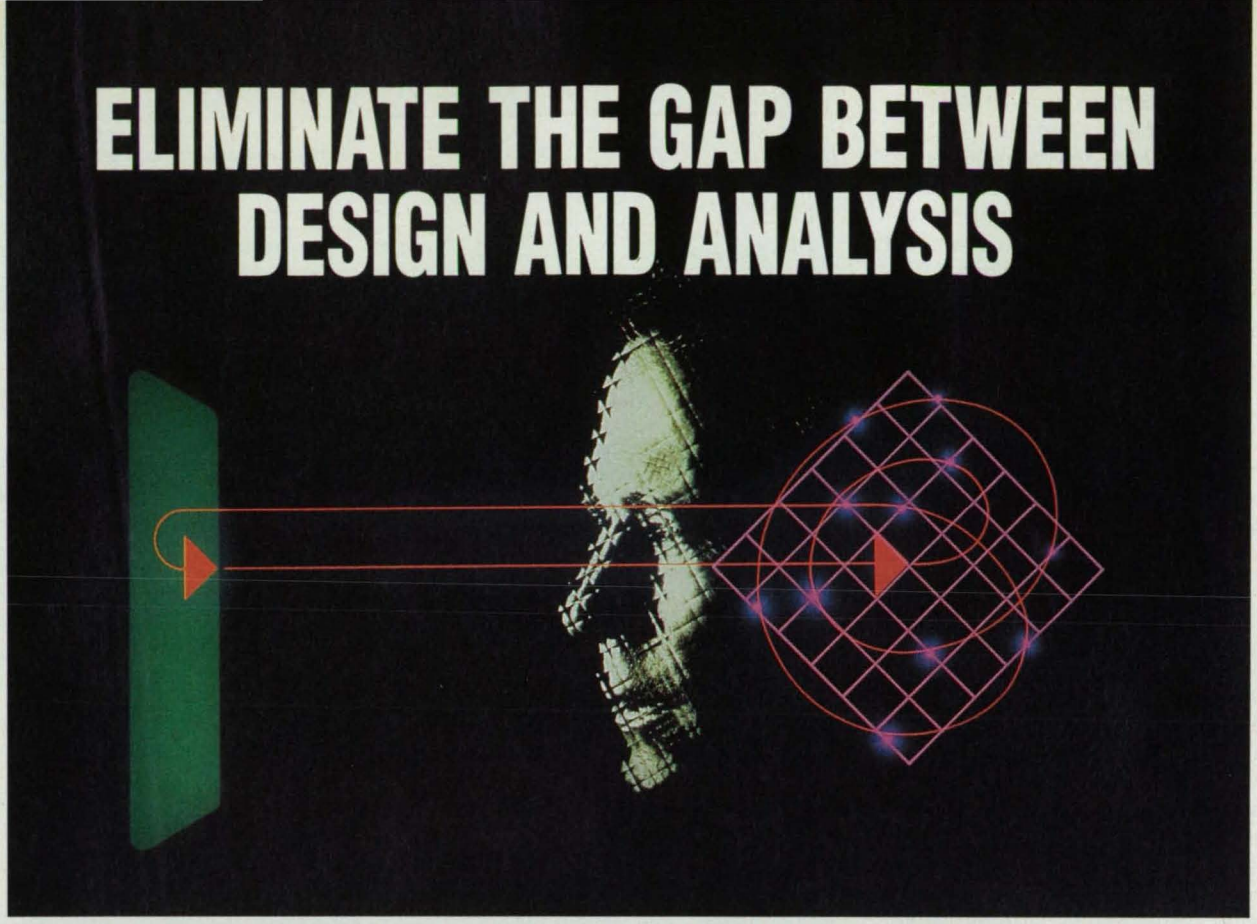
Novel molecular-weight-controlled end-capped poly(arylene ether benzimidazole)s (PAEBI's) were prepared by the nucleophilic displacement reaction of di(hydroxy)benzimidazole monomers with activated aromatic dihalides. The polymers were prepared at various molecular weights by upsetting the stoichiometry of the monomers and end-capped with a monohydroxybenzimidazole. The polymerizations were performed in the presence of alkali metal bases in polar aprotic solvents at elevated temperatures. This work demonstrated the effect of molecular weight on the physical and mechanical properties of these polymers. Compared to commercial polybenzimidazole, these polymers exhibit improved solubility in polar aprotic solvents and better compression moldability. Poly(arylene ether benzimidazole)s have potential applications as adhesives, coatings, films, fibers, membranes, moldings, and composite matrix resins.

The synthesis of a representative molecular-weight-controlled end-capped PAEBI is depicted in the figure. Polymers prepared at stoichiometric imbalances of 0 to 7 mole percent were pre-



End-Capped Poly(Arylene Ether Benzimidazoles) were prepared from monomers with activated aromatic dihalides as shown.

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pared and characterized. The effect of molecular weight on inherent viscosity, glass transition temperature (Tg), and dynamic thermal stability is presented in Table 1. The Tg and thermal stability were only slightly affected by the decrease in molecular weight. The effect of molecular weight on unoriented thin-film tensile properties is presented in Table 2. The films exhibited excellent tensile properties at 23 and 232 °C. Molecular-weight reduction did not have a major effect on thin-film properties. As expected, the moldability of the polymer powders improved substantially as the molecular weight decreased. Titanium-to-titanium adhesive specimens fabricated from PAEBI prepared at 3 mole percent stoichiometric offset by heating to 330 °C under 1.7 MPa for 15 min exhibited tensile shear strengths of 17.4 and 15.7 MPa, respectively, when tested at 23 and 232 °C. The titanium adhesive specimens exhibited no reduction in strength after isothermal aging for 1,000 h at 200 °C in flowing air. Unidirectional carbon-fiber-reinforced composites were fabricated from the PAEBI prepared at a 7 mole percent stoichiometric offset by heating solution-coated (drum-wound) prepreg to 360 °C under 1.4 MPa for 1 h. The preliminary unidirectional carbon-fiber (AS-4) composite properties (Table 3) exhibit excellent properties at 23 °C and respectable properties when tested at 200 and 232 °C. Controlled-molecular-weight, end-capped PAEBI exhibited improved processability without significant reduction in Tg or mechanical properties. In addition, PAEBI exhibited excellent adhesion to copper, and thin-film tensile properties were relatively unaffected by submersion for 167 h in hydraulic fluid, jet fuel and methylene chloride.

TABLE 1: PHYSICAL CHARACTERIZATION

	Stoichiometric Imbalance, Mole %				
Property	0	1.5	3.0	5.0	7.0
$\overline{M}_n$ (Calculated)	—	46,367	23,008	13,665	9,661
Inherent Viscosity, dL/g	1.99	1.65	1.42	0.84	0.55
T_g, °C (Powder)	276	274	274	269	266
Temperature of 5% Weight Loss Air/Nitrogen (TGA), °C	476/515	467/511	467/507	477/510	470/472

TABLE 2: UNORIENTED THIN FILM TENSILE PROPERTIES

Stoichiometric Imbalance, Mole %	Test Temperature, °C	Tensile Strength, MPa	Tensile Modulus, GPa	Elongation, %
0	23	125	4.1	14
	232	85	2.8	7
1.5	23	125	3.6	12
	232	81	2.6	5
3.0	23	129	4.0	30
	232	83	2.8	12
5.0	23	118	3.5	13
	232	66	2.3	8
7.0	23	114	3.6	22
	232	71	2.6	10

TABLE 3: PRELIMINARY UNIDIRECTIONAL CARBON FIBER COMPOSITE PROPERTIES

Test Temperature, °C	Flexural Strength, MPa	Flexural Modulus, GPa	Compressive Strength, GPa	Compressive Modulus, GPa
23	1,910	136	1,115	116
200	1,290	108	—	—
232	1,124	100	—	—

These Tables of Physical Properties illustrate the thermal stability and the excellent tensile strength of several PAEBI neat polymers and one composite.

This work was done by John W. Connell and Paul M. Hergenrother of **Langley Research Center** *and Joseph G. Smith, Jr., of the University of Akron. For further information, Circle 87 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Langley Research Center [see page 20]. Refer to LAR-14924.

Polyimides Made From 4,4′-Isophthaloyldiphthalic Anhydride

High-performance, thermoplastic, amorphous, and semicrystalline materials have been obtained.

Langley Research Center, Hampton, Virginia

Many polyimides, because of their versatility, processability, and high thermo-oxidative stability have become preeminent as technologically and commercially viable materials for applications in which thermally stable, heteroaromatic compounds are required. One area of application is in the manufacture of lighter and stronger aircraft and spacecraft structures. LaRC-TPI is a thermoplastic polyimide well known as a high-performance material. It is derived from 3,3′,4,4′-benzophenonetetracarboxylic dianhydride (BTDA) and 3,3′-diaminobenzophenone (3,3′-DABP) and is prepared in 2-methoxyethyl ether (diglyme). It was invented at NASA Langley Research Center and is a commercially available product. The similarity of 4,4′-isophthaloyldiphthalic anhydride (IDPA) to BTDA prompted a study to determine whether a polyimide made with the BTDA-like IDPA would possess the thermo-oxidative stability and other properties of such other polyimides as LaRC-TPI.

In experiments, twelve high-temperature, high-performance polyimide compositions based on IDPA were prepared and characterized. Tough, film-forming, polyimides insoluble in organic solvents were obtained in most cases. Three materials were semicrystalline. These materials offer the potential for the development of semicrystalline polyimides that have enhanced resistances to solvents and caustic chemicals, higher tensile strengths and moduli, enhanced thermo-oxidative stabilities below their melting temperatures, and enhanced melt processability, especially when heated to the melting tempera-

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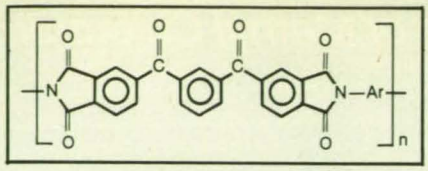
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tures. In comparison with Kapton H® polyimide film, several of the polyimides exhibited excellent long-term thermo-oxidative stability when subjected to isothermal thermogravimetric analysis (ITGA) at temperatures of 300 °C and 350 °C in air.

One material displayed different levels of semicrystallinity over a wide range of final curing times and temperatures. This material, made from IDPA and 1,3-bis(4-aminophenoxy-4′-benzoyl)benzene (BABB) exhibited multiple crystallization and melting behavior, implying the existence of two kinetic and two thermodynamic crystallization and melting transitions. These IDPA polyimides (see figure) typically form materials of high molecular weight. Films of the polyimides cast from N,N-dimethylacetamide (DMAc) are usually creasable and lightly colored and have glass-transition temperatures between 188 and 303 °C,



This is the **General Structure of a Polyimide Made From IDPA**. "Ar" denotes the radical derived from a corresponding amine, and *n* is an integer.

as determined by differential scanning calorimetry (DSC). They are all insoluble in hot, highly polar solvents like m-cresol and dimethyl acetamide after curing at a temperature of 300 °C in air. The long-term thermo-oxidative stabilities of these materials were found to be excellent at 300 °C and 350 °C in air. Several compositions were found by DSC and wide angle x-ray scattering to be semicrystalline. These novel materials, which have controlled levels of crystallinity and excellent resistance to chemicals at high temperatures, are valuable additions to the polyimide family of coatings and films.

This work was done by J. Richard Pratt of Lockheed Company, Terry L. St. Clair and Vernon L. Bell of **Langley Research Center**, *Carol Gautreaux of Analytical Services and Materials, Inc., and Margaret Gerber of Lockheed Company. For further information, Circle 14 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 20]. Refer to LAR-14194.

Poly(Arylene Ether Imidazole) Surface Films

These films adhere well to some substrates, provide smooth surfaces, and facilitate release from molds.

Langley Research Center, Hampton, Virginia

Thin films of thermoplastic poly(arylene ether imidazole)s (PAEI's) have been found to be particularly suitable for use as surface modifiers for graphite/epoxy or graphite/bismaleimide composite panels. A molecule of PAEI includes imidazole groups along its backbone that co-cure (i.e., react chemically) with epoxies or bismaleimides during processing. This co-curing provides excellent adhesion between PAEI films and the graphite/epoxy or graphite/bismaleimide panels.

If a PAEI film is applied to such a panel during processing in a smooth mold, then the as-processed panel has a smooth (specular) surface. Thus, there is no need for postmachining or polishing of PAEI-processed parts made of neat-resin epoxies and/or bismaleimides or made of composites of epoxies and/or bismaleimides that may contain any type of continuous or chopped fibers or fabrics. Additionally, PAEI films are readily released from smooth glass or stainless-steel molds, so that no release agent is necessary. The adhesion between the PAEI films and the panels remains even after thermal cycling from room temperature to about −196 °C. PAEI films are thermally stable and resistant to bombardment by energetic electrons.

Figure 1 provides a molecular-level schematic representation of the interface between a PAEI film and a graphite/epoxy facesheet. The chemical reaction between the epoxy and the PAEI makes this interface more stable than an interface based on secondary adhesive forces, which occurs when a nonreactive film like Kapton® (or equivalent) polyimide is used. The interface formed between the epoxy and the PAEI film results in better thermal-cycling behavior because a gradient in chemical composition is formed between the two layers: presumably this gradient is accompanied by a gradient in the coefficient of thermal expansion between that of the PAEI film and that of the epoxy. In contrast, a nonreactive film can disbond after prolonged thermal cycling because of the accumulation of stresses caused by the mismatch between the coefficients of thermal expansion of the film and the epoxy.

The following example illustrates the use of a PAEI thermoplastic film in the manufacture of a precise composite-material reflector panel: A PAEI film 50 μm thick was placed directly against a precision convex paraboloidal glass tool 36 cm in diameter. The perimeter of the film was affixed to the glass tool by use of double-sided adhesive tape. A 25-cm-diameter, uncured, eight-ply, quasi-isotropic prepreg tape layup composed of T50 carbon fiber with ERL-1962 epoxy resin was placed on top of the PAEI film and glass tool. The entire tool and layup were vacuum bagged and heated to 177 °C under a pressure of 0.7 MPa in an autoclave; this caused

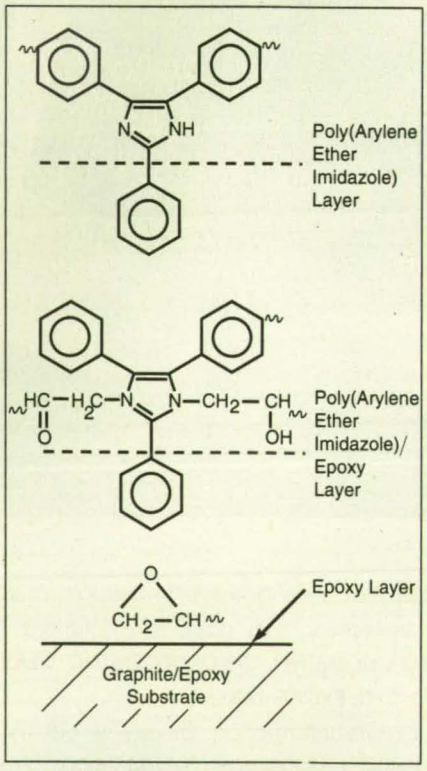


Figure 1. The **Interface** between a graphite/epoxy substrate and a surface film of PAEI contains molecular bonds and gradients of chemical composition and thermal expansion.

the epoxy to cure and to bond chemically to the surface of the PAEI film.

Next, a 5-cm-thick, graphite/phenolic composite honeycomb core material and a T50/ERL-1962 composite face-

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For More Information Circle No. 506

sheet were adhesively bonded to the back of the laminate (the side without the PAEI film). After the adhesive cured, the entire resulting panel was lifted from the glass tool, and the excess PAEI film was trimmed from the edge of the panel. The panel had a precise concave paraboloidal contour with the PAEI film bonded to the surface providing a glasslike finish. The final reflector surface (see Figure 2) was produced by vapor deposition of a reflective aluminum layer 500 Å thick onto the surface of the PAEI without any pretreatment or polishing. A layer of silicon monoxide 500 Å thick was deposited on the aluminum. The accuracy of the reflector surface was determined with an infrared laser interferometer and was measured to be 1.8 μm root-mean-square over the entire 25-cm diameter. The paraboloidal composite reflector had an areal weight of 5.7 kg/m^2.

This work was done by John W. Connell, Timothy W. Towell, and Stephen S. Tompkins of **Langley Research Center**. *For further information, Circle 40 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Langley Research Center [see page 20]. Refer to LAR-14812

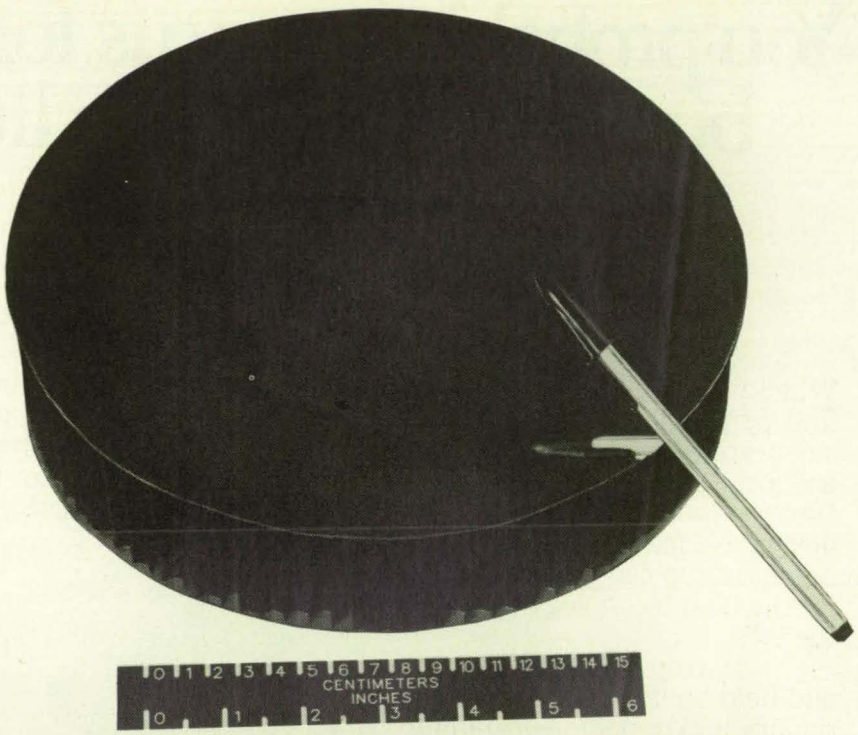
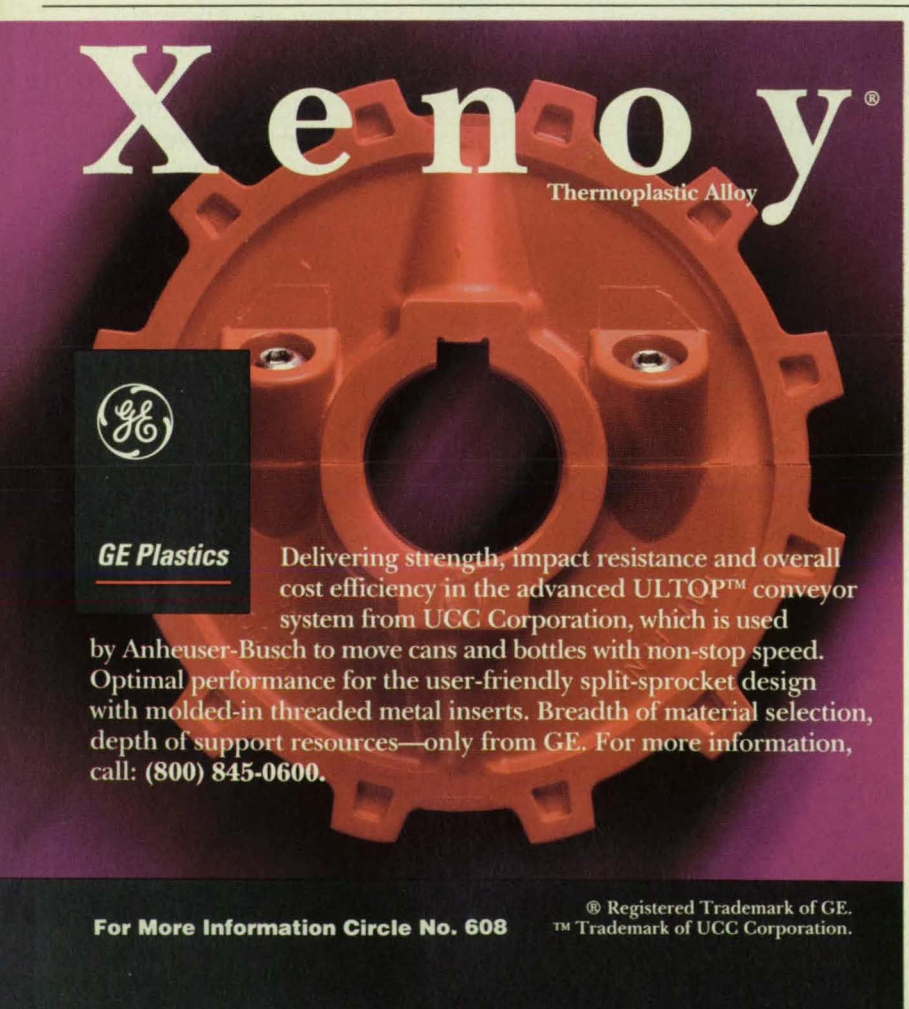


Figure 2. A **Paraboloidal Reflector** was molded as a unitary composite laminate panel with PAEI surface film. The surface film was then aluminized for reflectivity.



Prestressed Composite Parts

The well-known prestressing concept would be applied to smaller components.

Marshall Space Flight Center, Alabama

Matrix/fiber structural components would be strengthened by prestressing, according to a proposal. As in larger structural components (e.g., concrete beams reinforced with steel bars), prestressing would increase the effective tensile strengths of the components, enabling the components to function in applications in which they would otherwise fail.

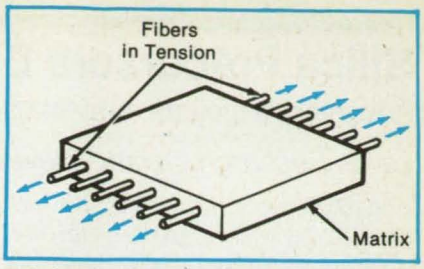
The basic idea in prestressing is to maintain a permanent compressive stress in a structural material that is weak in tension but strong in compression: this compressive stress should be large enough that when an external load is applied to the structural component, the net load in the tensionally weak material is still compressive. In the case of a matrix/fiber composite material, the fibers (which are typically strong in tension) could be used to prestress the matrix (which is typically weak in tension) in compression.

In the fabrication of a prestressed ma-

trix/fiber composite part, the fibers would be placed in tension while they were being encapsulated in the matrix material (see figure). After completion of the encapsulation process (including curing of the matrix material), the fibers would be released from the external equipment that imposed the tension, causing the fibers to pull the matrix material into compression.

A variety of fiber/matrix combinations could be fabricated in this way. For example, prestressed quartz fibers could be encapsulated in a ceramic matrix. The resulting composite could be used to make a blade for a gas turbine. The ceramic, normally weak in tension, would have high strength and would endure high temperature.

This work was done by Michael M. Surls of United Technologies Corp. for **Marshall Space Flight Center**. *No further documentation is available.*
MFS-28676



Reinforcing Fibers Are Stretched while they are encapsulated in a matrix. After encapsulation, the fibers are released, placing the matrix in lengthwise compression.

Freeze-Drying Makes Improved IPN and Semi-IPN Polymers

Fracture toughnesses and thermal/mechanical performances of polyimides are enhanced.

Langley Research Center, Hampton, Virginia

Highly cross-linked polyimides are inherently brittle and prone to microcracking in thermally cycled fiber composites. A novel process has been developed for the production of interpenetrating polymer networks (IPN's) or semi-IPN's with greater fracture toughness and resistance to microcracks. This process controls the degree of phase separation in the IPN's.

Traditionally, IPN's have been made by using a common solvent for two different organic constituents and then evaporating the solvent. One or both of these constituents may have reactive end caps, producing semi-IPN's or full IPN's, respectively. During the evaporation process, the oligomer and polymer components separate because of differences in solubilities as the solution is concentrated. The thermodynamic dependence of the solubility of a constituent with removal of solvent strongly influences separation of phases and thus the microstructures of the IPN's.

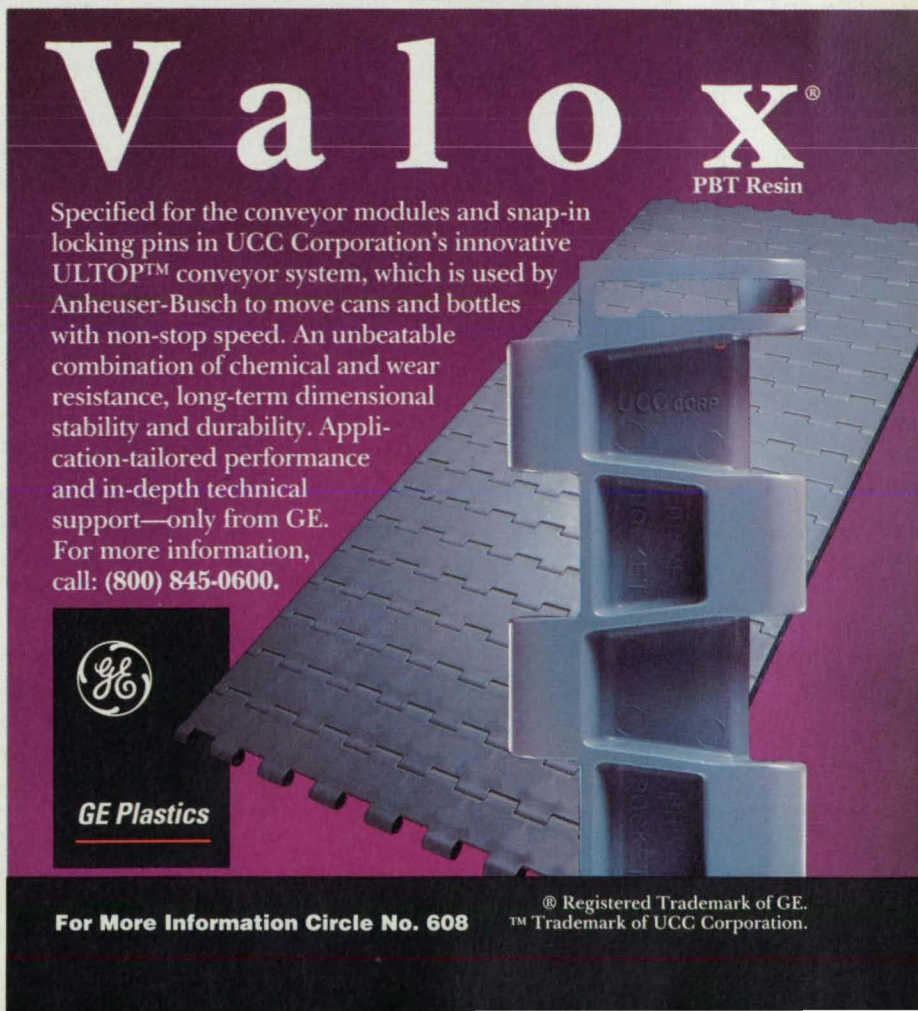
The novel process involves freeze-drying. The solvent is removed by rapidly removing energy from the liquid at ambient pressure. The solution of oligomer and polymer constituents is thermally quenched to a solid in a very short time. The thermodynamic state of the two organic constituents in the solid is metastable. A small amount of energy is put into the system to enhance sublimation, but the temperature of the solid is kept below the triple point of the solvent. The remaining solid material is a microporous open-cell foam of the minimally phase-separated constituents.

A solvent suitable for use in the freeze-drying process can be either a solid, liquid, or gas at ambient temperature and pressure. As an example, 1,3,5-trioxane is an excellent solid solvent for the freeze-drying process. It can easily be sublimed at room temperature at a subambient pressure and can dissolve both an imide thermoset oligomer and a thermoplastic polyimide in the amic acid form. Suitable liquid solvents are numerous. Carbon dioxide (CO_2) is a good example of a suitable gas solvent.

In a control experiment, IPN's and semi-IPN's were formed by dissolving the constituents in another common solvent in the traditional method. The neat resins and composite materials thus produced were tested for both the traditional and freeze-drying processes. In all cases, glass-transition temperatures and data from dynamic mechanical tests of the freeze-dried IPN's and semi-IPN's demonstrated that the freeze-drying process provided much improved IPN's and semi-IPN's.

This work was done by Ruth H. Pater, Ricky E. Smith, and Ruperto T. Razon of **Langley Research Center**; *Marion G. Hansen and Hahn J. Hsiung of the University of Tennessee; and Mark D. Soucek of the National Research Council. For further information, Circle 7 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 20]. Refer to LAR-14677.



Silica Precursors Derived From TEOS

Advantages include easy-to-use liquid forms and high char yields.

Lewis Research Center, Cleveland, Ohio

In recent years, the need for high-temperature, lightweight, oxidation-resistant materials has directed attention toward the synthesis and fabrication of refractory silicates, such as aluminum silicate and mullite. Their use is of interest in the formation of monolithics and fiber-reinforced ceramic composites in jet-engine components.

Early investigators studied sol-gels for this purpose. Their results indicate that, while they are well suited for silicate-powder synthesis, sol-gels have limited application in fabricating ceramic articles. The high-solvent content of sol-gels results in low-oxide char yields in the range of 10 to 15%. This low yield results in considerable shrinkage in processing sol-gels to the final densified product.

To overcome these difficulties, two high-char-yield polysiloxane polymers have been developed. They are designated as TEOS-A and TEOS-B with silica char yields of 55% and 22%, respectively. These free-flowing polymers are Newtonium liquids instead of thick gels. They are easily synthesized by the controlled hydrolysis of inexpensive tetraethoxysilane (TEOS).

The higher-molecular-weight TEOS-A is a gluelike adhesive liquid of viscosity 8,000 to 12,000 c.p., whereas TEOS-B is a more-fluid liquid of viscosity 150 to 200 c.p. The synthesis of TEOS-A or TEOS-B depends on the mole ratio of H_2O/TEOS used in the hydrolysis reaction. Both precursors are organic polymers that are miscible with such common organic solvents as toluene and ethanol, but immiscible with water.

The adhesive properties of TEOS-A suggest its use as a binder for the fabrication of ceramic articles from oxide powders. On cold-pressing an oxide powder such as alumina or silica mixed with TEOS-A binder, "green" (in the sense of uncured) bodies of good mechanical strength are obtained. When these "green" body compacts are heated to about 120 °C, the TEOS-A binder thermosets to a hard, cross-linked polysiloxane, causing the solid oxide powder to be held in a solid polymer matrix that can be easily handled without damage. When the compact is heated, the polymer decomposes to form amorphous silica, which cements together the oxide grains via the formation of reaction-bonded silicate.

Unlike purely organic binders, which add no matter to the final compact, polysiloxanes contribute silica. When the purely organic binder burns off before the onset of sintering, there is no binder left to hold the compact together. On the other hand, with the polysiloxane binder, amorphous silica remains to cement the oxide grains together. By increasing the proportion of TEOS-A in the powder mixture, one produces a puttylike material that can readily be molded into complex shapes, then heated to turn the bodies thus shaped into ceramics.

The less-viscous and more-fluid lower-molecular-weight TEOS-B can be used to infiltrate already-formed porous ceramic compacts to increase their densities without effecting shrinkage. The vacuum infiltration of TEOS-B into a porous ceramic article followed by heating causes the pores to become filled with silica or silicates. Also, TEOS-B can be used as a paint to coat a substrate with silica. Another application of this precursor is to make highly pure silicate powders. In such a case, TEOS-B is mixed with the desired amount of oxide, then heated. The highly dispersed active amorphous silica thus produced readily reacts with the powdered oxide to produce silicates. Alternatively, the oxide powder can be alumina, in which case mullite can be made.

This work was done by Warren H. Philipp of **Lewis Research Center**. *Further information may be found in NASA TM-102489 [N90-21858], "Polysiloxanes Derived from the Controlled Hydrolysis of Tetraethoxysilane as Precursors to Silica for Use in Ceramic Processing."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700. LEW-15096

Plastic Foam Withstands Greater Temperatures and Pressures

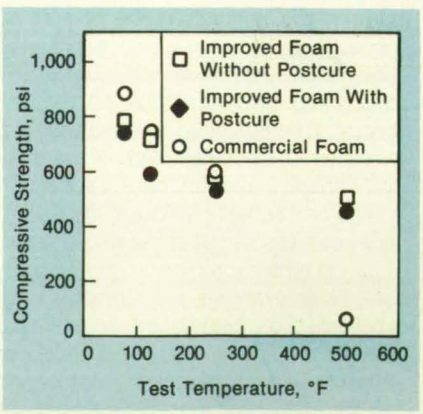
A machinable material withstands composite-processing conditions.

Marshall Space Flight Center, Alabama

An improved plastic foam is suitable for use in foam-core laminated composite parts and in tooling (molds, substrates, and mandrels) for making fiber/matrix-composite parts. In comparison with other plastic foams used heretofore in similar applications, this foam is stronger at high temperatures (see figure), more thermally and dimensionally stable, more machinable, more resistant to chemical degradation, and less expensive. It is compatible with a variety of matrix resins. The foam is made of a polyisocyanurate blown with carbon dioxide and has a density of 12 to 15 lb/ft^3 (192 to 240 kg/m^3).

The improved foam is formulated with commercial, readily available raw materials. Because it is blown with carbon dioxide rather than fluorocarbons, it does not contribute to depletion of ozone from the atmosphere. It is compatible with epoxy, bismaleimide, and phenolic resins. It can withstand the temperatures [up to 375°F (191°C)] and pressures [up to 135 psi (931 kPa)] at which composites that contain these resins are cured; it can also withstand postcuring at 475°F (246°C). Other foam-core materials tend to disintegrate under these conditions. The improved foam also shrinks less than the other foams do. At $17 per cubic foot ($600 per cubic meter) (1992 prices), the cost of this foam is less than one-third that of the commercial foam now used for the same purposes.

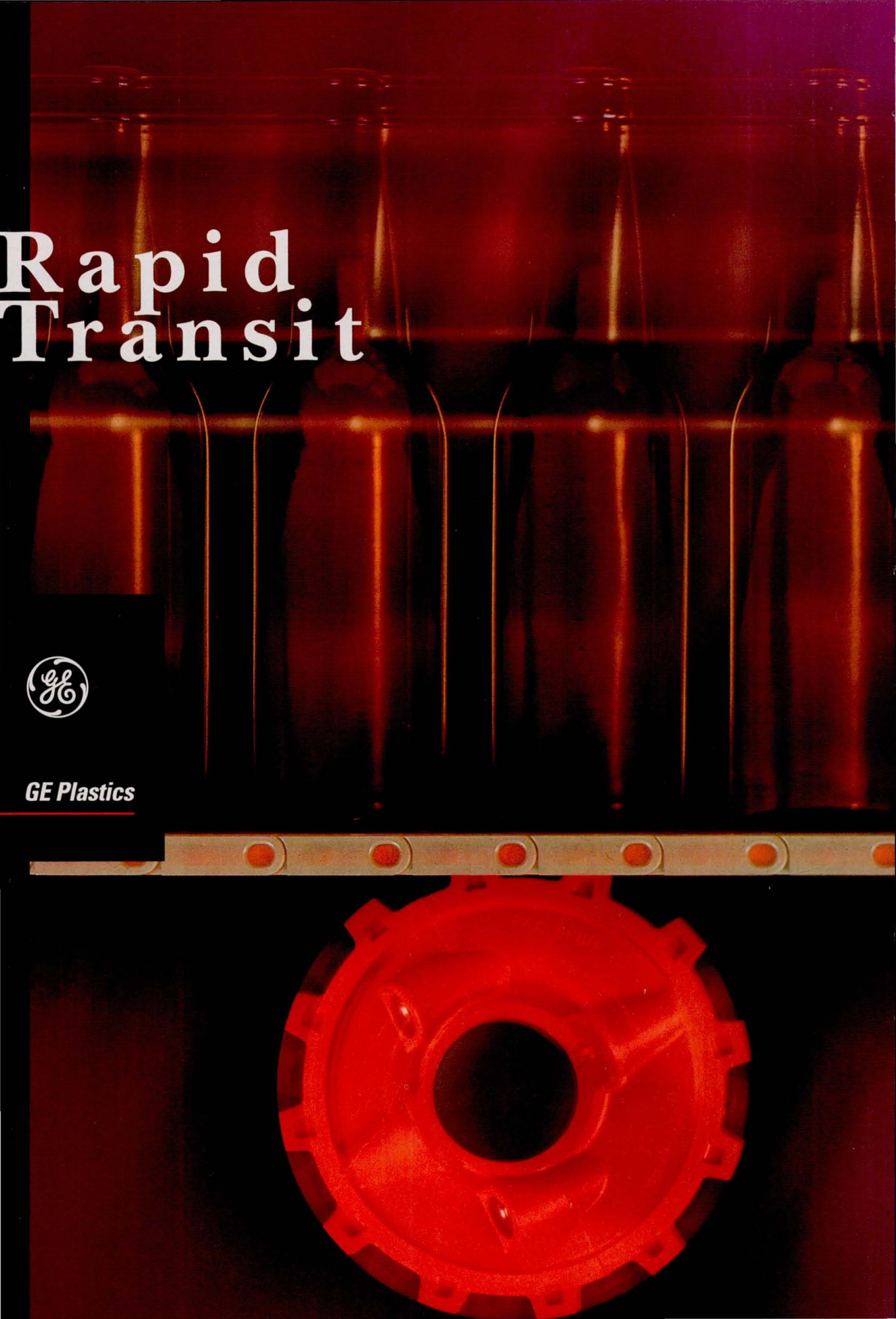
The improved foam could be used in



The Improved Polyisocyanurate Foam retains much of its compressive strength at 500 °F (260 °C). In contrast, a commercial foam-core material loses most of its strength at this temperature.

Rapid Transit

GE Plastics



the cores of composite panels in such diverse products as aircraft, automobiles, railroad cars, boats, and sporting equipment like surfboards, skis, and skateboards. It could also be used in thermally stable flotation devices in submersible vehicles. The improved foam can be machined into mandrels upon which filaments are wound to make shells. In some cases, layers of foam could be left in the shells to serve as thermal insulation.

This work was done by John A. Cranston and Doug MacArthur of Martin Marietta Corp. for **Marshall Space Flight Center**. *For further information, Circle 28 on the TSP Request Card.*

Title to this invention has been waived under the provisions of the National Aeronautics and Space Act [42 U.S.C 2457(f)], to Martin Marietta Astronautics Group. Inquiries concerning licenses for its commercial development should be addressed to

Martin Marietta Astronautics Group
Attn. Martin G. Anderson,
Intellectual Property
Assoc. General Counsel,
P.O. Box 179, Mail Stop DC-1010
Denver, CO 80201

Refer to MFS-28711, volume and number of this NASA Tech Briefs *issue, and the page number.*

Books and Reports

These reports, studies, handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Optimum Interfacial Layers for Fiber/Metal Composites

The effects of thickness, modulus of elasticity, and coefficient of thermal expansion are considered.

A report presents a theoretical stress-analysis study of some of the factors that affect the choice of a thin layer of material to be placed at the interface between each fiber and the matrix of a ceramic-fiber/metal-matrix composite. When the composite is cooled to room temperature from the higher temperature at which it is manufactured, the mismatch between the larger coefficient of thermal expansion of the matrix and the smaller coefficient of thermal expansion of the fibers introduces complicated residual stresses that can result in cracking. The interfacial layer is intended to reduce the residual stresses by absorbing some of the mismatch.

The mathematical model for the stress analysis was a cylinder composed of three concentric layers: a solid inner core that represented the fiber, a layer that represented the interfacial material surrounding the fiber core, and an outer layer that represented the matrix. The stress analysis considered only the residual stresses from one cool-down cycle. To simplify the stress analysis, the elastic and thermal-expansion properties of all three layers were taken to be isotropic and constant, and the analysis was limited to an elastic solution as a first approximation. In this analysis, the longitudinal stresses were decoupled from the transverse stresses.

Once the properties of the fiber and matrix materials are specified, the parameters to be varied in the optimization process are the thickness, modulus of elasticity, and coefficient of thermal expansion of the interfacial material. For this study, the criterion for optimization was chosen to be the minimization of the average density of the elastic-distortion energy in the interfacial layer and the matrix. [The distortional energy in the fiber was not considered because (1) this quantity was not appropriate to a failure criterion for a brittle material like that of the fiber and (2) the fiber was unlikely to fail in any event because the stress in it is compressive and the compressive strength of the fiber material was very high.]

A computer program was written to perform the stress analysis and optimization and was applied to several representative materials. The results of the computations indicate that the optimum thickness of the interfacial material is the largest allowable and that the optimum modulus of elasticity of the interfacial material is the smallest allowable, no matter what fiber and matrix materials are used. The results also indicate that the optimum coefficient of thermal expansion of the interfacial material is intermediate between those of the fiber and the matrix.

With this analysis, some materials were surveyed as candidates for use as interfacial material in some specific composites. It was found that only a few materials had optimum moduli of elasticity and optimum coefficients of thermal expansion. To increase the number of candidate interfacial materials, elements with less-than-optimum moduli and coefficients were also examined. The residual stresses in the matrices and interfacial materials were also calculated for composites that contained these interfacial materials.

This work was done by Bradley A. Lerch of **Lewis Research Center** *and Louis J. Ghosn of Sverdrup Technology, Inc. Further information may be found in NASA TM-102295 [N89-27223], "Optimum Interface Properties for Metal Matrix Composites."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700. LEW-15101

Properties of Carbon/Carbon and Carbon/Phenolic Composites

Charts and tables document an extensive series of tests.

A 194-page report presents data on the physical properties of carbon-fiber-reinforced carbon-matrix and phenolic-matrix composite materials. The data are based on tests conducted on panels, cylinders, blocks, and formed parts. The test specimens were fabricated by standard processes for fiber-reinforced composites. The data can be used by designers to analyze thermal-response and stress levels and develop structural systems that ensure high reliability at minimum weight.

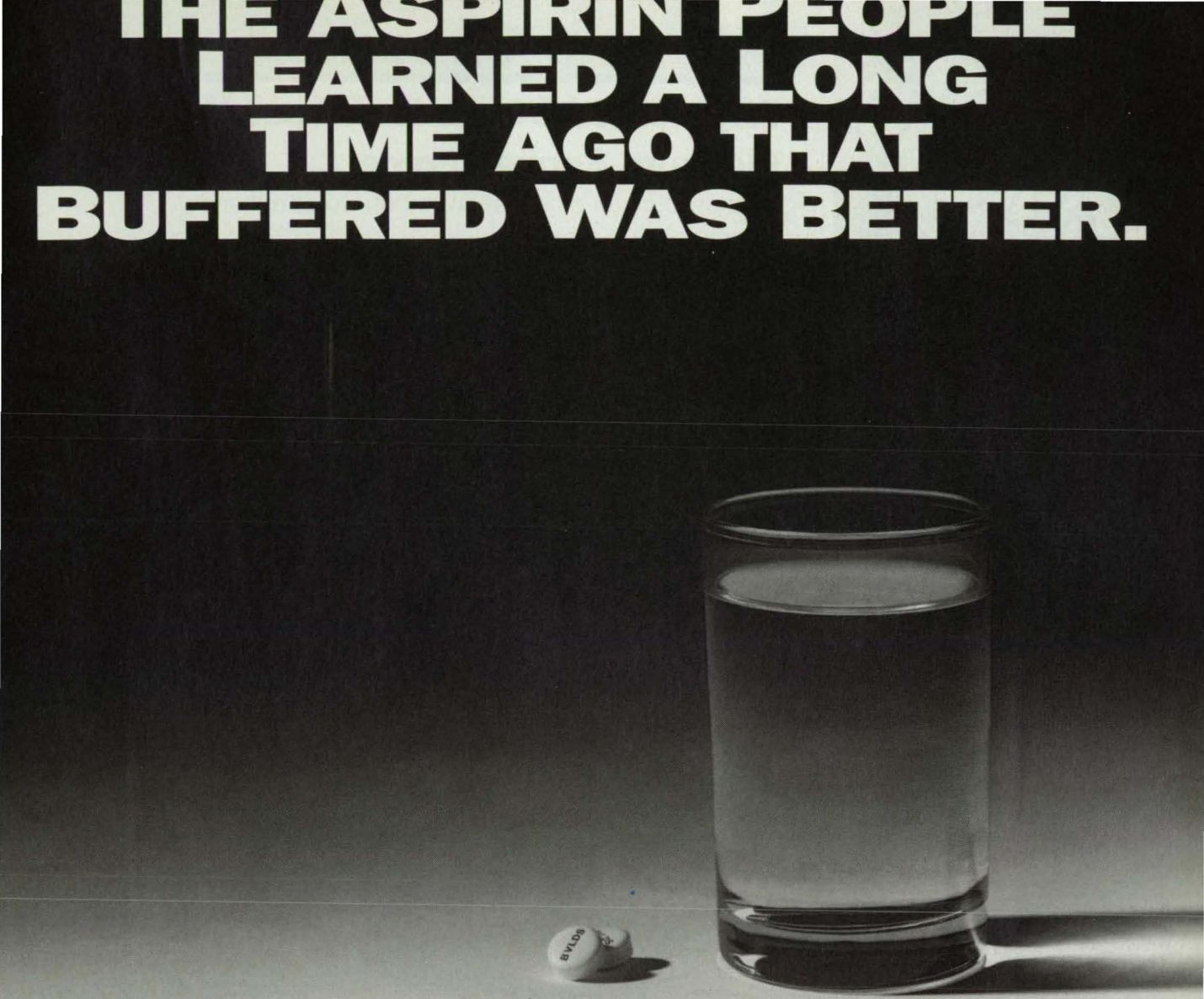
The data are given in charts and tables. They include enthalpies; heat capacities; and coefficients of thermal expansion and thermal conductivities in the warp, fill, and warp/fill directions. Other data that are presented include average compression moduli, compression ultimate strengths, ultimate strains, and shear strengths. The data were taken at temperatures from 0 to 5,000 °F (−18 to 2,760 °C).

This work was done by John R. Mathis and A. R. Canfield of Thiokol Corp. for **Marshall Space Flight Center**.
MFS-28698

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Electronic Components and Circuits

Augmented Computer Mouse Would Measure Applied Force

Data on force (or other varying input) would enhance interaction with the user.

Lyndon B. Johnson Space Center, Houston, Texas

A proposed computer mouse would measure the force of contact applied by the user. This measurement would add another dimension to the two-dimensional-position-measuring capability of the conventional computer mouse; that is, the force measurement could be designated to represent any desired continuously variable function of time and position, such as a control force, acceleration, velocity, or position along an axis perpendicular to the computer video display. The proposed mouse could enhance the sense of realism and intuition in the interaction between the operator and the computer. As such, it would be useful in such applications as three-dimensional computer graphics, computer games, and mathematical modeling of dynamics.

A typical conventional mouse includes rollers or optical sensors that measure the position of the mouse in the *x*–*y* plane, plus a multiplexer and analog-to-digital converter through which the position measurements are transmitted to the computer. In addition, it includes one or more on/off button switches that are pressed by the operator to mark desired positions and/or transmit other information of a binary nature. The proposed mouse would include all of the foregoing circuitry, except that in addition to or in place of the on/off switches, there would be one or more force sensors and the associated circuitry.

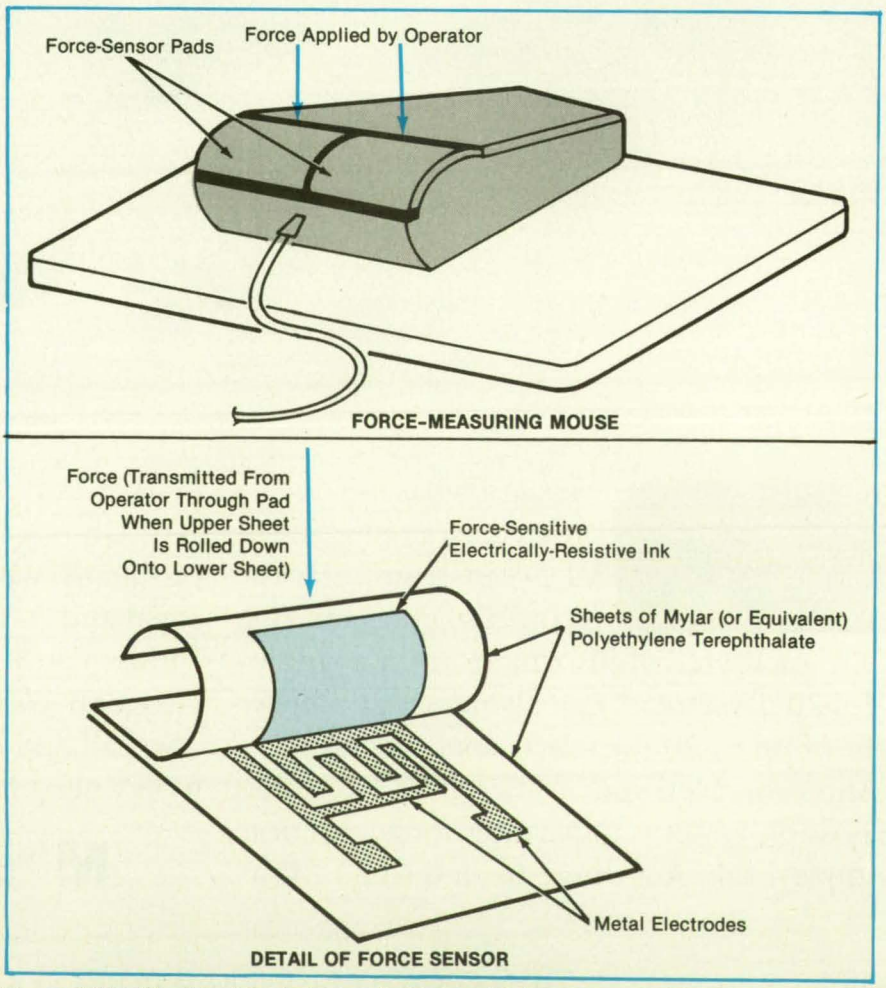


Figure 1. The **Electrical Resistance of a Layer of Ink** in contact with metal electrodes would vary with the force applied by the operator.

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For More Information Circle No. 647

Each force sensor would be a thin, sandwichlike assembly. It would include interdigitated metal electrodes mounted on an insulating plastic sheet in contact with a layer of force-sensitive electrically resistive ink on another plastic sheet (see Figure 1). The resistance of the ink, and thereby the applied force, would be sensed by incorporating the ink resistor into a simple operational-amplifier voltage-dividing and low-pass-filtering circuit. The output of this sensing circuit would be digitized and sent to the computer along with the position measurements (see Figure 2). The mouse-driving software in the computer would decode the digitized resistance (force) data and pass them on to the application program.

Of course, the augmented mouse could be made to operate in the conventional on/off mode by designating threshold "on" and "off" force levels. To prevent oscillations between "on" and "off" and oversensitivity to unintended small variations in applied forces, the "on" threshold level should exceed the "off" threshold level by a suitable dead band. This force-sensor concept could also be applied to computer keyboards; for example, in an electronic piano, pushing harder on a key could increase the gain of an amplifier, causing the note to be played louder.

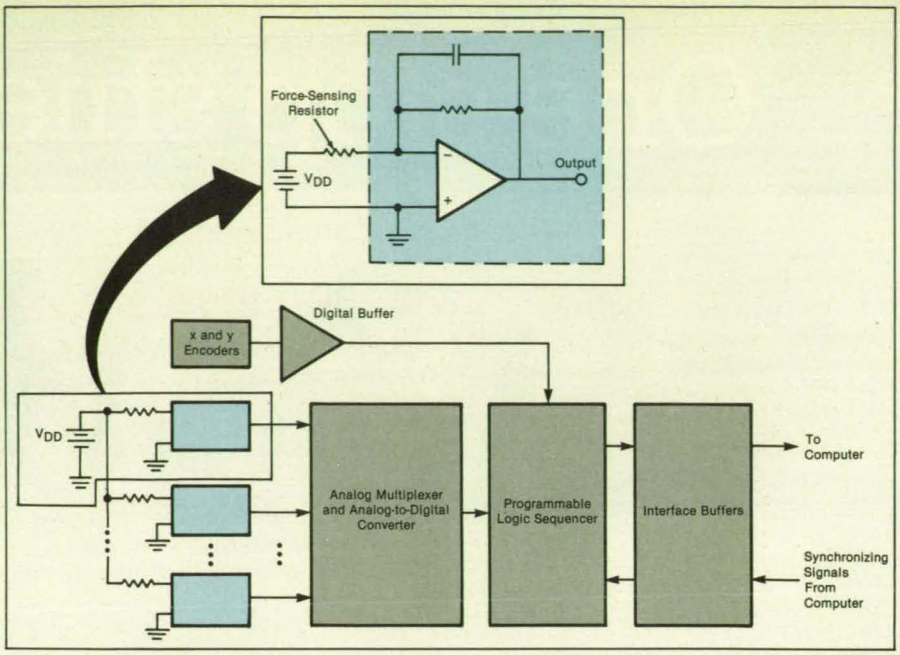


Figure 2. These **Signal-Processing Circuits** would be included in the mouse along with the force sensor(s).

This work was done by Larry C. H. Li of **Johnson Space Center**. *For further information, Circle 4 on the TSP Request Card.*
MSC-21876

Sandwich-Geometry $YBa_2Cu_3O_{7-\delta}$/Au/Nb SNS Devices

Results show promise for manufacture of practical devices.

NASA's Jet Propulsion Laboratory, Pasadena, California

Superconductor/normal-conductor/superconductor (SNS) devices in which the electronically active layers consist of the high-temperature superconductor $YBa_2Cu_3O_{7-\delta}$, the normal conductor Au, and the conventional superconductor Nb, respectively, have been fabricated in sandwich geometry. These devices and the processes by which they are fabricated are being investigated as part of a continuing effort to develop SNS microbridges for use in superconducting quantum interference devices (SQUID's) or as mixers or local oscillators that operate at frequencies of hundreds of gigahertz. These sandwich-geometry SNS devices have been used to determine the physical properties of the materials in them and their performances as electronic devices, all with a view toward improving the fabrication processes.

Several variations of the fabrication process were tried. Thin films of $YBa_2Cu_3O_{7-\delta}$ were deposited by laser ablation to a thickness of 1,000 to 3,000 Å: some on (100) cubic zirconia substrates, others on (100) $LaAlO_3$ substrates. During deposition, the films were heated to temperatures of 700 to 750 °C in an atmosphere of oxygen at a pressure of 10 mtorr (1.3 Pa). After deposition of the $YBa_2Cu_3O_{7-\delta}$, the pressure of the oxygen was increased to 800 mtorr (107 Pa) at the high temperature;

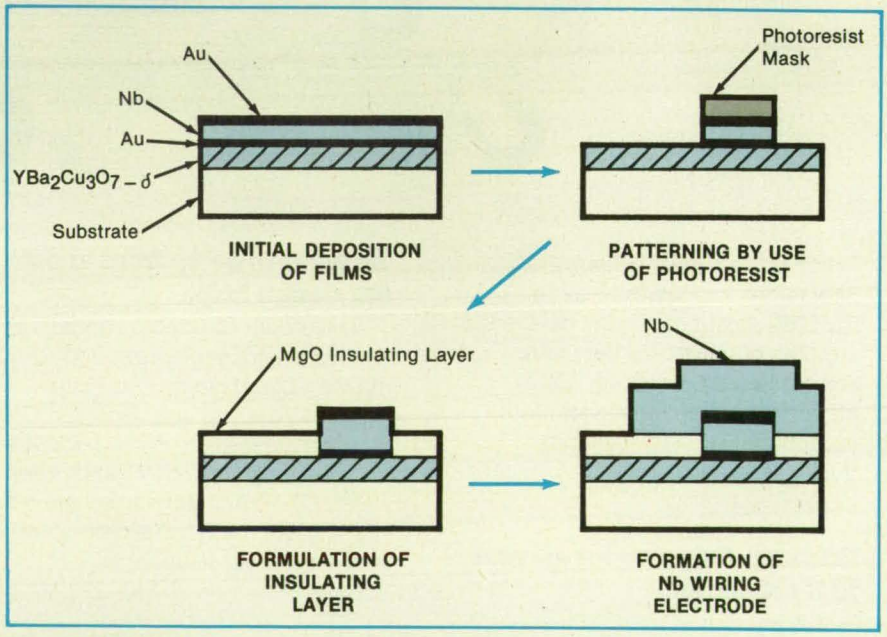


Figure 1. **SNS Devices** are fabricated in a multistage process in which a square array of them is formed on a substrate. A cross section of one of the devices is shown here schematically at selected stages of the process.

then, depending on the particular specimen, one of two subprocesses was carried out: Either (1) the specimen was immediately cooled to 450 °C and annealed in oxygen at 500 torr (6.7×10^4 Pa) for 30 minutes, then the atmosphere was changed to Ar at 10 mtorr (1.3 Pa), the temperature of the specimen was reduced below 100 °C, and gold was deposited on it; or else (2) the specimen was cooled to room temperature, then gold was deposited on it as described above, then the specimen was sub-

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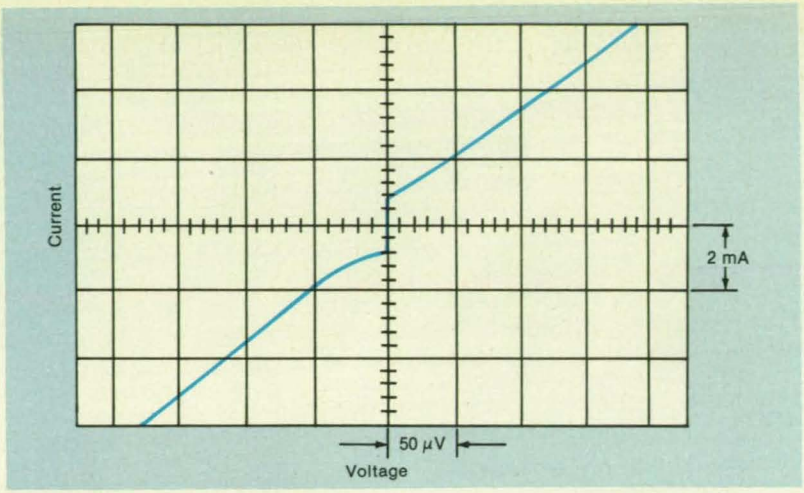


Figure 2. **This Current-vs.-Voltage** curve was measured on a 5 x 5 μm square device and indicates a critical current density of 3,800 A/cm2.



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jected to the high-temperature oxygen anneal.

In either case, the thickness of the gold layer was 100 to 600 Å. Next, a top layer of Nb 2,000 Å thick and a cap layer of Au 100 to 300 Å thick were deposited in a 10-mtorr (1.3-Pa) atmosphere of argon. All of these depositions were performed without breaking the vacuum in the deposition chamber, other than to backfill with O_2 or Ar as described above.

In a subprocess that included photoresist masking, reactive-ion etching, argon-ion milling, resist stripping, and argon-ion sputtering, each specimen substrate and its deposited layers were patterned into a square array of SNS devices. In a further subprocess, each device was provided with an electron-beam-deposited insulating layer of MgO and an Nb wiring electrode 2,000 Å thick (see Figure 1).

The resulting devices were immersed in, or suspended over, liquid He, and their electronic characteristics at various temperatures were measured by a four-probe technique. Supercurrents and the ac Josephson effect were observed at temperatures $\lesssim$ 8K. The R_nA products (where R_n = the resistance of the device in the normally-conducting, high-current regime and A = the cross-sectional area that it presents to the electrical current) of the best devices were found to be as low as 6×10^{-9} Ω•cm^2, and critical currents (see Figure 2) were found to be as high as 5.2 kA/cm^2. These were the devices that were annealed in oxygen after the deposition of gold and before the deposition of niobium.

This work was done by Marc C. Foote and Brian D. Hunt of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 20 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 20]. Refer to NPO-18394.

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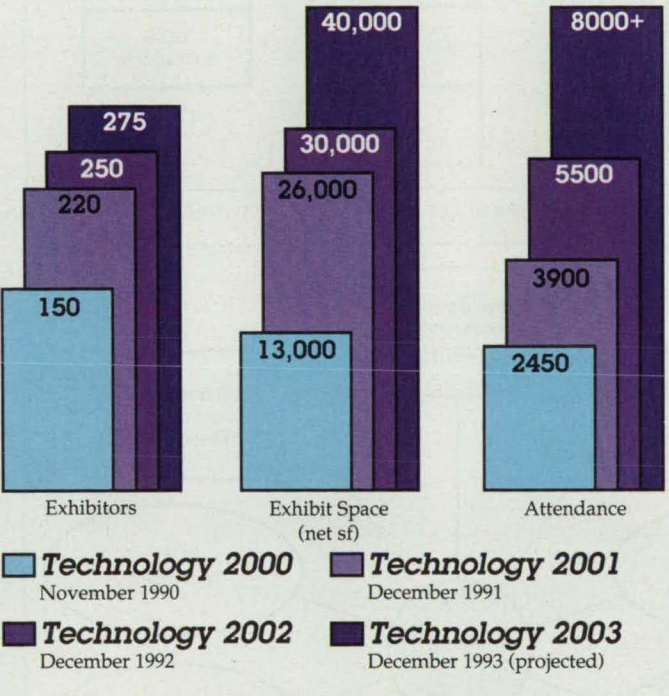
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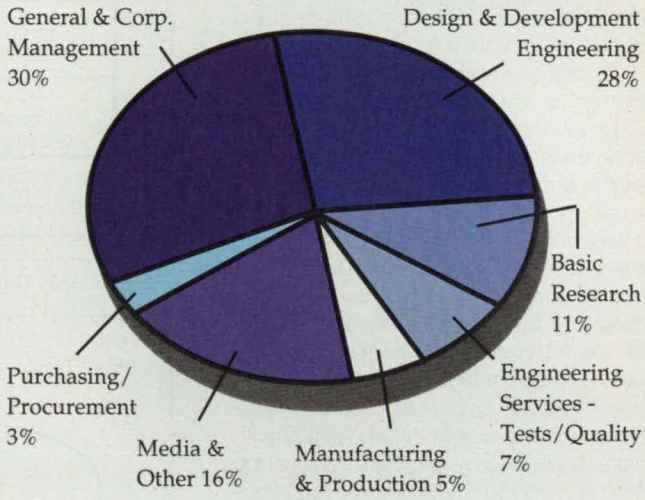
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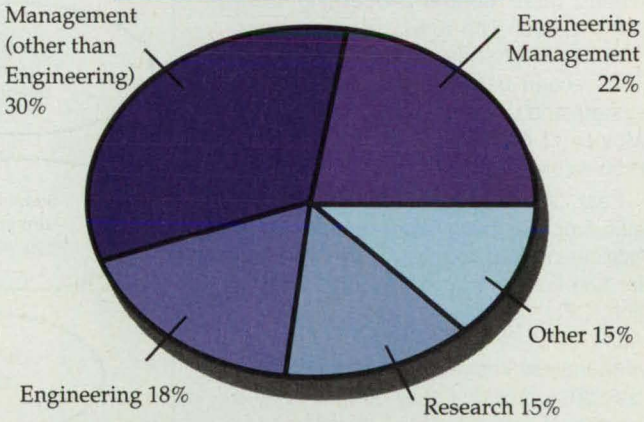
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Multiple-User, Multitasking, Virtual-Memory Computer System

Laboratory instruments and computer workstations have fast access to large memories.

Lewis Research Center, Cleveland, Ohio

A computer system has been designed and programmed to serve multiple (of the order of 25 to 48) users in a research laboratory. The system provides for the computer control and monitoring of laboratory instruments, acquisition and analysis of data from those instruments, and interaction with users via remote terminals. To each instrument and terminal, the system provides fast access to the shared central processing units and the associated large (from megabytes to gigabytes) memories. The underlying concept of the system is also applicable to monitoring and control of industrial processes.

Of course, economy is the primary motivation for sharing computing resources. Expensive equipment like array processors, image processors, terminals, printers, and color plotters can be shared at a cost much lower than that of dedicating a separate computer and peripheral equipment to each project. Software for the control of instruments and the acquisition of data, and the data themselves, can also be shared. Heretofore, most software for use with laboratory instrumentation has been based on single-user operating systems, and the lack of the necessary software has inhibited researchers from making the transition to multiple-user, multitasking, virtual-memory computing systems.

The computer system (see Figure 1) includes three central processing units (CPU's), each with 16-Mbytes of memory. Two 474-Mbyte hard disks are attached. The second hard disk is for backup of system and user software. Generally, 16 Mbytes of memory are required for the processing of large data arrays.

Each CPU (subsystem) has a major specific function. CPU 1 is designed to analyze data and contains an array processor for fast Fourier transformations. In addition, CPU 1 shares an image processor with CPU 2. CPU 2 is designed to display and analyze images. A 32-Gbyte optical disk drive provides easy access to, and storage of, images. CPU 3 is designed to acquire data and contains 8 general-purpose interface bus (GPIB) channels (ports) and an analog-to-digital (A/D) input/output interface with 16 channels. As many as nine users can use the third CPU simultaneously to acquire data.

It is important to note that, although each

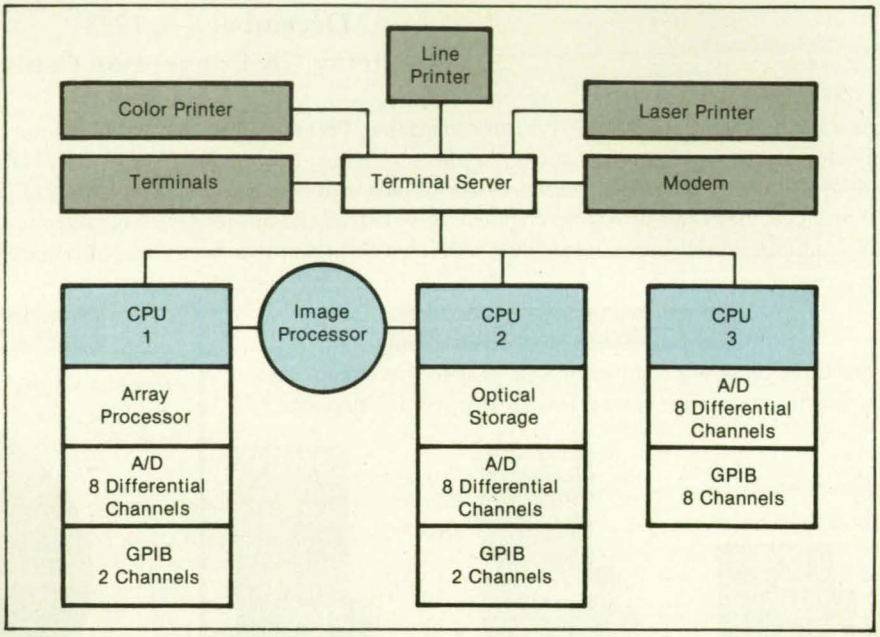


Figure 1. This **Computer System** serves about 25 to 48 users simultaneously.

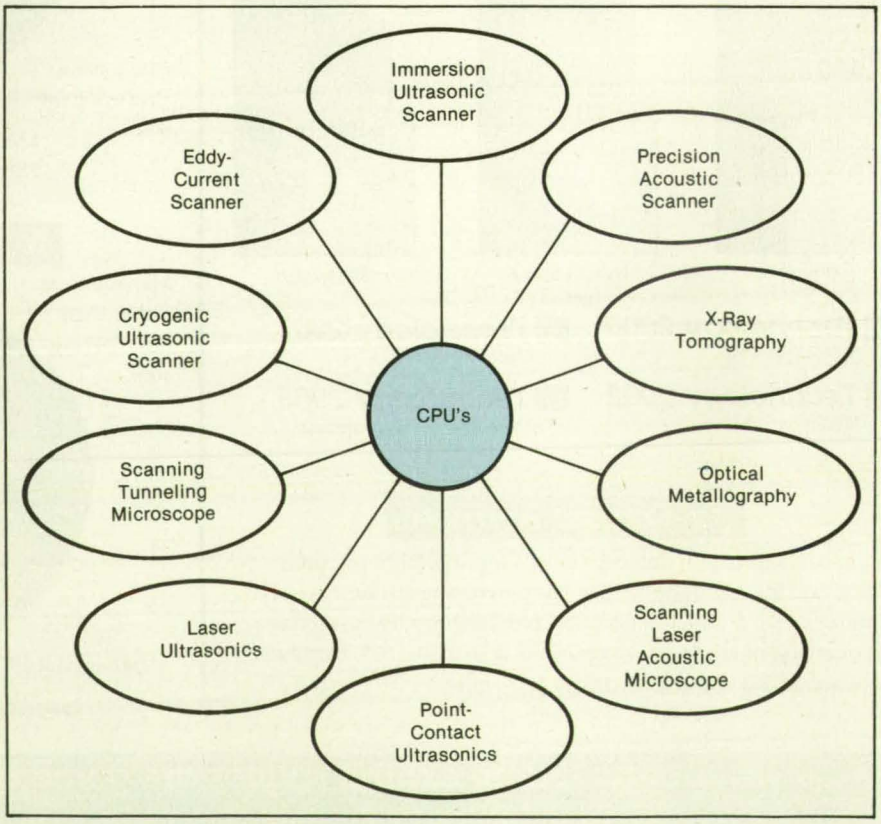


Figure 2. **Multiple Instruments of a Non-Destructive-Evaluation Group** can be connected to a computer system like the one shown in Figure 1.



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CPU subsystem has been designed for a specific function, it is not limited to that function. Therefore, CPU's 1 and 2 also include GPIB and A/D interfaces. A total of 15 researchers can acquire data or control instruments simultaneously via the GPIB or A/D interfaces. Additional users may be simultaneously analyzing data, processing images, developing software, and generating reports.

The three CPU's are connected via an Ethernet for easy transfer of files between systems. A terminal server connected to the Ethernet provides for remote access by multiple users to each of the CPU's. Thus, terminals and instruments can be placed at different locations throughout the site. Modems attached directly to the CPU or Ethernet provide access to the system from remote locations off the site. Modems are used to initiate, stop, or check the statuses of experiments on evenings and weekends.

Figure 2 shows a typical configuration for a non-destructive-evaluation research group. Recently, GPIB extenders have been made available by several manufacturers. By use of these extenders, instruments can be placed at locations remote from the CPU's. The GPIB extenders are transparent to the researchers' software.

The multiple-user software subsystem includes a number of routines for the acquisition of data and the control of instruments via the GPIB. These routines are written in the FORTRAN and BASIC computing languages. Preliminary experience has shown that when computer programs and instruments are easily shared, researchers develop new programs rapidly to suit their particular needs, principally by modifying existing programs. Thus, the fundamental software is expanded and finely tuned to form a versatile system.

This work was done by Edward R. Generazio and Don J. Roth of **Lewis Research Center** *and David B. Stang of Sverdrup Technology, Inc. For further information, Circle 13 on the TSP Request Card.*
LEW-15295

Fiber-Coupled Acousto-Optical-Filter Spectrometer

Advantages include compactness, speed, and no moving parts.

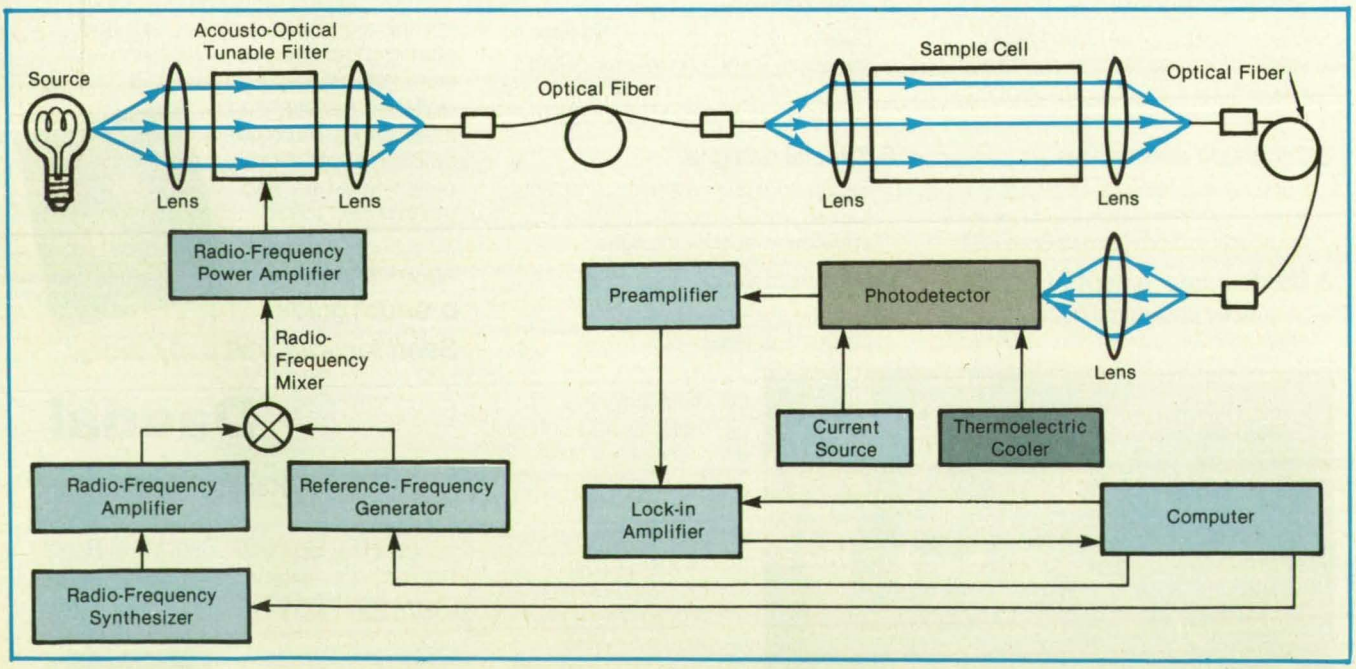
Lyndon B. Johnson Space Center, Houston, Texas

The spectrometer illustrated schematically in the figure is based on a tunable monochromator in the form of a birefringent acousto-optical filter. Visible or infrared light from a hot-wire source (e.g., a light bulb) is collimated into the fiber, which is a crystal of tellurium dioxide. An acoustic wave propagates across the crystal from a transducer on one side. The transducer is driven at a radio frequency (typically between 10 and 100 MHz). Part of the collimated infrared light at a wavelength that depends on this frequency is diffracted by the acousto-optical effect toward a second lens and focused into an optical filter of zirconium fluoride glass.

The fiber carries the light to a remote sample cell similarly equipped with lenses. After passing through the cell, the light travels along another optical fiber to a thermoelectrically cooled PbSe photodetector. The output of the photodetector is preamplified, lock-in-amplified, digitized, then analyzed by a computer. The same computer also controls the frequency of the signal that drives the transducer.

The computer can be programmed to operate the spectrometer in a scanning mode, in which the transducer-driving frequency is stepped in small increments to step the wavelength in small increments across the spectrum between two specified wavelengths. Alternatively, the computer can be programmed to command a random-access or "hopping" mode, in which the transducer-driving frequency is shifted abruptly to make the wavelength jump through a sequence of specified discrete values. This hopping mode would be useful in monitoring the variation, with time, of the concentrations of several substances in a sample, the wavelengths in the sequence being the wavelengths of spectral peaks known to be those of the substances of interest.

The optical-fiber coupling makes it possible to monitor samples in remote, hazardous, or confined locations. The zirconium fluoride glass fibers can transmit at wavelengths from about 400 nm to 5 μm. In comparison with other monochromators, the acousto-optical tunable filter is compact and can be scanned rapidly, without the use of moving parts. Furthermore, the sequence of wavelengths can be chosen essentially at will to satisfy specific diagnostic requirements. Potential applications



The **Fiber-Coupled Acousto-Optical-Filter Spectrometer** can step rapidly through a commanded sequence of wavelengths. The sample cell can be located remotely from the monochromator and the associated electronic circuitry, connected to them with optical fibers.

for spectrometers of this kind include the control of chemical processes, medical diagnoses, spectral imaging, and sampling of atmospheres.

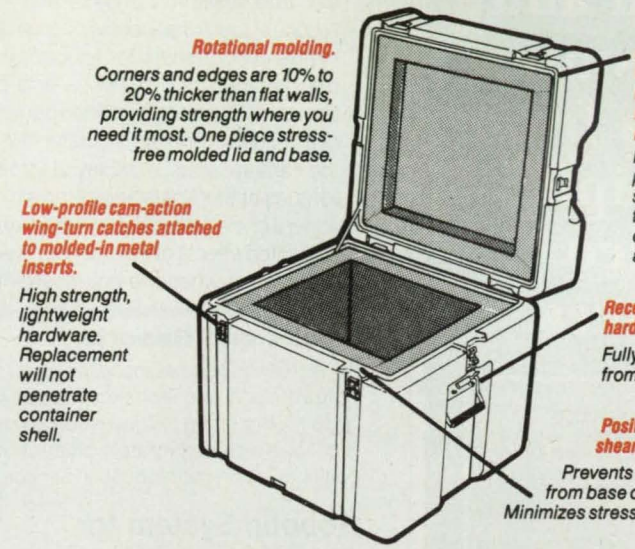
This work was done by Kenneth H. Levin and Frank Yanan Li of Infrared Fiber Systems, Inc., for **Johnson Space Center**. *For further information, Circle 73 on the TSP Request Card.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

George Hooley, Director of Finance
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2301-A Broadbirch Drive
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Refer to MSC-21859, volume and number of this NASA Tech Briefs *issue, and the page number.*

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Laboratory for Telerobotic Repair

The performances of a robot and a human operator are measured in specific tasks.

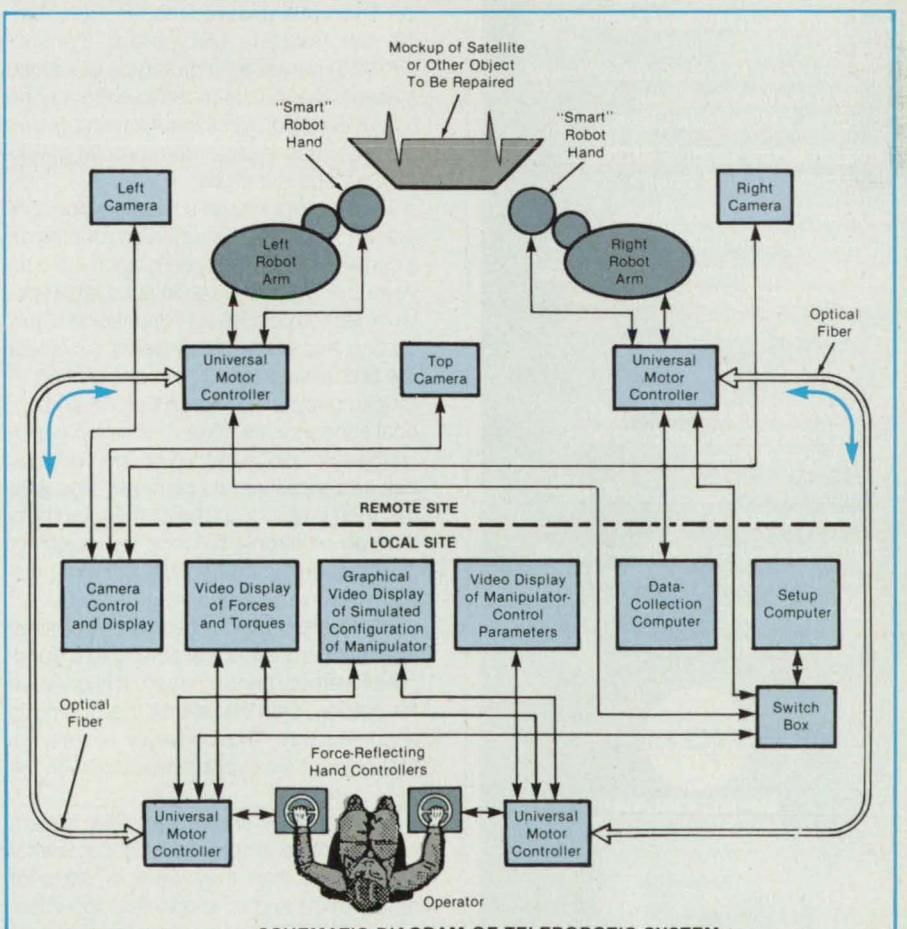
NASA's Jet Propulsion Laboratory, Pasadena, California

A laboratory telerobotic system can perform such complicated tasks as picking up tools, removing a thermal blanket, and replacing screws. The system is being used to perform research and to develop telerobotic-repair capabilities equal to those of a human operator.

The interim goal of research on the system is to duplicate the tasks that were performed in 1984 by two astronauts, who, in the orbiting Space Shuttle, replaced the modular attitude-control subsystem and the main electronics box on the Solar Max Satellite. The research is expected to reveal information about suitable tasks for teleoperated repairs, developing specific task-control policies, training in virtual environments, and teleoperation of redundant manipulators.

The telerobotic system comprises two parts: a satellite simulator and an assembly of other laboratory equipment. The simulator consists of a mockup of the Solar Max Satellite, an illumination subsystem, and the repair tools. The assembly of other laboratory equipment (see figure) includes the following:

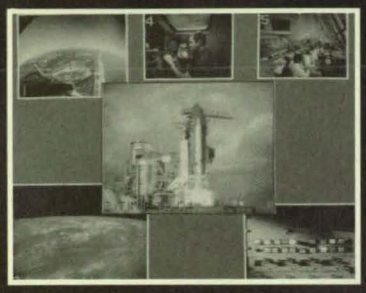
- A camera-positioning subsystem that now



SCHEMATIC DIAGRAM OF TELEROBOTIC SYSTEM

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supports three (but could support five) cameras with control of pan, tilt, zoom, focus, and iris;
- A dual-arm robot with "smart" hands and software for force feedback, servocontrol, and collection of data; and
- A control room that contains force-reflecting hand controllers for teleoperation of the manipulators, switches and potentiometers for setting the video parameters of the video cameras, monitors that show the camera views, a display of forces and torques at the wrists and of forces on the fingers of the manipulator, a display of the simulated effects of the operator's actions (to be used when the actual effects are delayed by transmission time), and a video display through which the operator can monitor and modify the manipulator-control parameters.

To date, the laboratory telerobotic system has yielded the first results that quantify and evaluate position control with sensor-based force feedback in repair tasks. Previously, feedback and repair tasks had been characterized separately.

This work was done by Paolo Fiorini, Antal K. Bejczy, Hari Das, and Haya Zak of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 54 on the TSP Request Card.*
NPO-18637

Books and Reports

These reports, studies, handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Robotic System for Greenhouse or Nursery

About 90 percent of robotic cycles are successful.

A report presents additional information about the robotic system described in "Robotic Gripper With Force Control and Optical Sensors" (MFS-28537), *NASA Tech Briefs*, Vol. 16, No. 6 (June 1992), page 76. This system, called the "Flexible Agricultural Robotics Manipulator System" (FARMS) serves as a prototype of robotic systems that are intended to enhance the productivities of agricultural assembly-line-type facilities in large commercial greenhouses and nurseries.

The system includes a robotic-vision subsystem that detects a geranium cutting on a conveyor belt. The system stops the conveyor belt while the vision subsystem determines the position and orientation of this cutting and other subsystems complete the processing of the previous cutting. A robotic gripper with force control and optical sensors in its fingers closes in gently on the stem of the cutting on the conveyor belt and measures its diameter. The gripper then (1) picks up the cutting and puts it on an electronic balance for weighing; (2) transfers the cutting to a trimming station, where unwanted leaves are cut off and the stem is trimmed to the desired length; (3) transfers the cutting to a bend-measurement sensor, where it is oriented for potting; then (4) inserts the cutting in a potting tray. The conveyor is then restarted, and the cycle is repeated with the next cutting.

The operation and design of the system are described in this report in somewhat more detail than they were in the prior noted article and its supporting documentation. The report contains three sections: Section I presents a brief discussion of the motivation for the development of the particular robotic sytem in the context of the economic need to enhance productivity of greenhouses and nurseries. Section II presents some technical details, including descriptions of (1) the tasks to be performed by the robotic gripper and the tasks to be performed by the rest of the system (called the "robotic work cell"); (2) the subsystems and the sequence of operations they perform on a cutting during a robotic cycle; (3) the equipment modules of the robotic-gripper subsystem and some engineering considerations that affect their designs; and (4) software for the control of the robotic gripper. Section III reports, among other things, that initial tests showed that the system does not crush or bruise cuttings, that it operates successfully in 90 percent of robotic cycles, and that although the cycle time of the robot could potentially be 1 to 2 seconds, it is lengthened to 6 to 7 seconds by the slowness of operation of the optical sensors.

This work was done by Paul Gill of **Marshall Space Flight Center**; *Jim Montgomery, John Silver, and Neil Heffelfinger of Martin Marietta Corp.; and Ward Simonton and Jim Pease of the University of Georgia. To obtain a copy of the report, "Flexible Agricultural Robotics Manipulator System," Circle 52 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center *[see page 20]*. *Refer to MFS-28584.*

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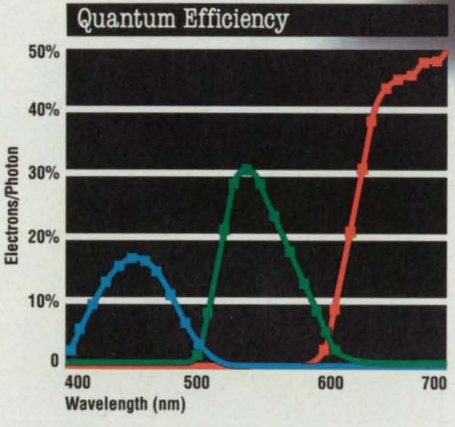
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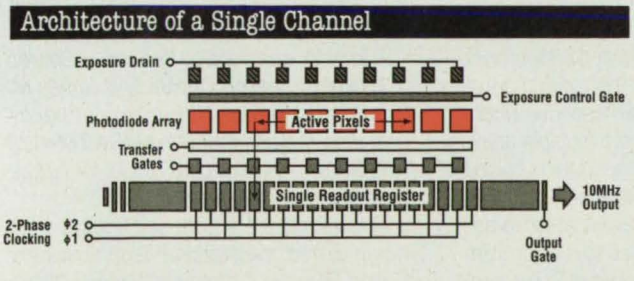


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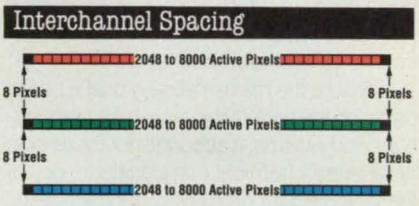


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Predicting Failure Behaviors of Thermoset Polymers

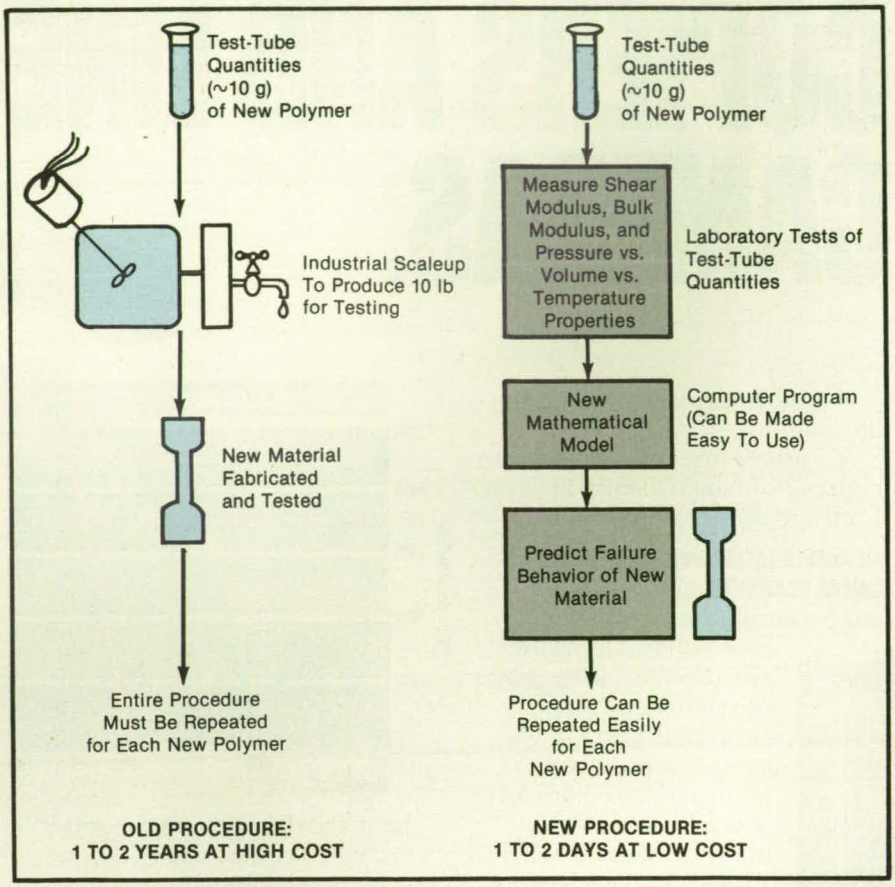
Useful predictions can be made from measurements on test-tube quantities.

Lewis Research Center, Cleveland, Ohio

A mathematical model for the viscoelastic failure behavior of an epoxy or other thermoset polymer can reduce considerably the time and expense necessary to evaluate a new polymer (see figure). Heretofore, to evaluate the behavior of a new polymer even partially, it has been necessary to prepare a quantity of the order of 10 lb (4.5 kg) and to subject the material to an extensive series of tests. By use of the new mathematical model, one can quickly obtain first-order estimates of the viscoelastic properties and, thereby, decide more easily whether the material should be rejected or is a good candidate for more thorough evaluation. The only properties required by the model are the equilibrium pressure vs. volume vs. temperature (PVT) response and the linear viscoelastic shear and bulk moduli — properties that can be determined quickly from experiments on test-tube quantities.

Because the mathematical model is based partly on the underlying molecular deformation mechanisms, it accounts for the effects of different chemical compositions, densities of molecular cross-links, functionalities of curing agents, and the like on the nonlinear stress-vs.-strain response. The model, which contains no adjustable parameters, has the form of a constitutive equation that describes (1) the nonlinear viscoelastic behavior, including yield, when the polymer is in the solid state; (2) the glass-transition phenomenon; and (3) the non-Newtonian flow behavior of the polymer melt. In the most general form of the model, the viscoelastic dissipation is represented as occurring on a material time scale that is controlled by the nonequilibrium entropy. This time scale incorporates the fact that on the molecular level, the rate of viscoelastic relaxation changes with the thermodynamic state of the polymer (i.e., temperature, pressure, and specific volume).

The complete model is complicated but can be simplified to one of three limiting forms, depending on the specific phenomena to be included or excluded. For isothermal deformations in the solid, the model becomes an equation for the history of the stress response as a function of the histories of the displacement, viscoelastic shear and bulk moduli, pressure, volume, and temperature. For temperatures in the glass-transition region, the model becomes an equation for the history of pressure as a function of the equilibrium pressure, the volume, and the histories of the strains and the bulk modulus. The model can also be simplified somewhat to describe the non-Newtonian flow of an un-cross-linked polymer melt.



The **Evaluation of a New Polymer** can be speeded considerably by adopting a procedure based on the new mathematical model of viscoelastic failure behavior.

The model has led to the development of a novel procedure for the extraction of the linear viscoelastic shear response when, as in many epoxies, there are multiple relaxation mechanisms. The procedure is based on the assumption that there are two such mechanisms: one that prevails at temperatures near that of the glass-to-rubber transition and another that prevails at lower temperatures. The viscoelastic response is taken to be a linear combination of the response of the two mechanisms and is analyzed by spectral-decomposition techniques. The model has been tested against some experimental data. It was found to predict fairly accurately the stress-vs.-strain response of an epoxy tensile specimen. It also proved fairly accurate in predicting the volume-vs.-temperature response and glass-transition temperature of poly(vinyl acetate).

This work was done by Kenneth J. Bowles of **Lewis Research Center** *and James M. Caruthers of Purdue University. Further information may be found in NASA TM-4128 [N89-25300], "A Predictive Model for Failure Properties of Thermoset Resins."*

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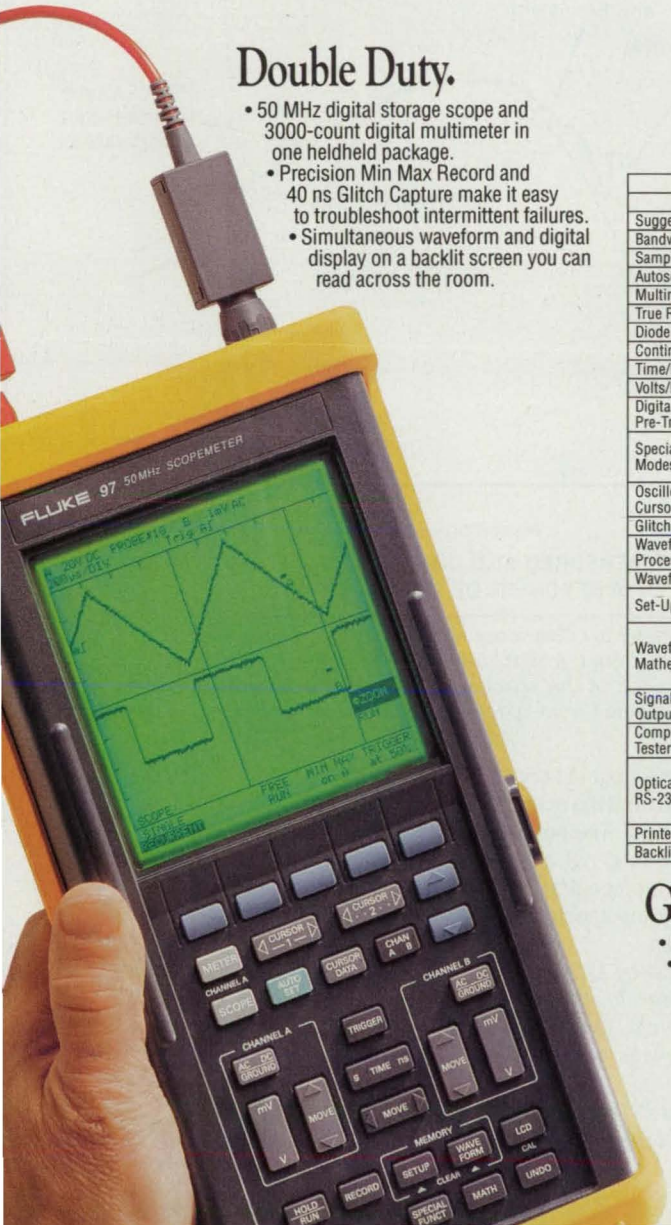
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For More Information Circle No. 451

Multiwavelength Pyrometry To Correct for Reflections

Computerized curve fitting yields more and better information on thermal radiation.

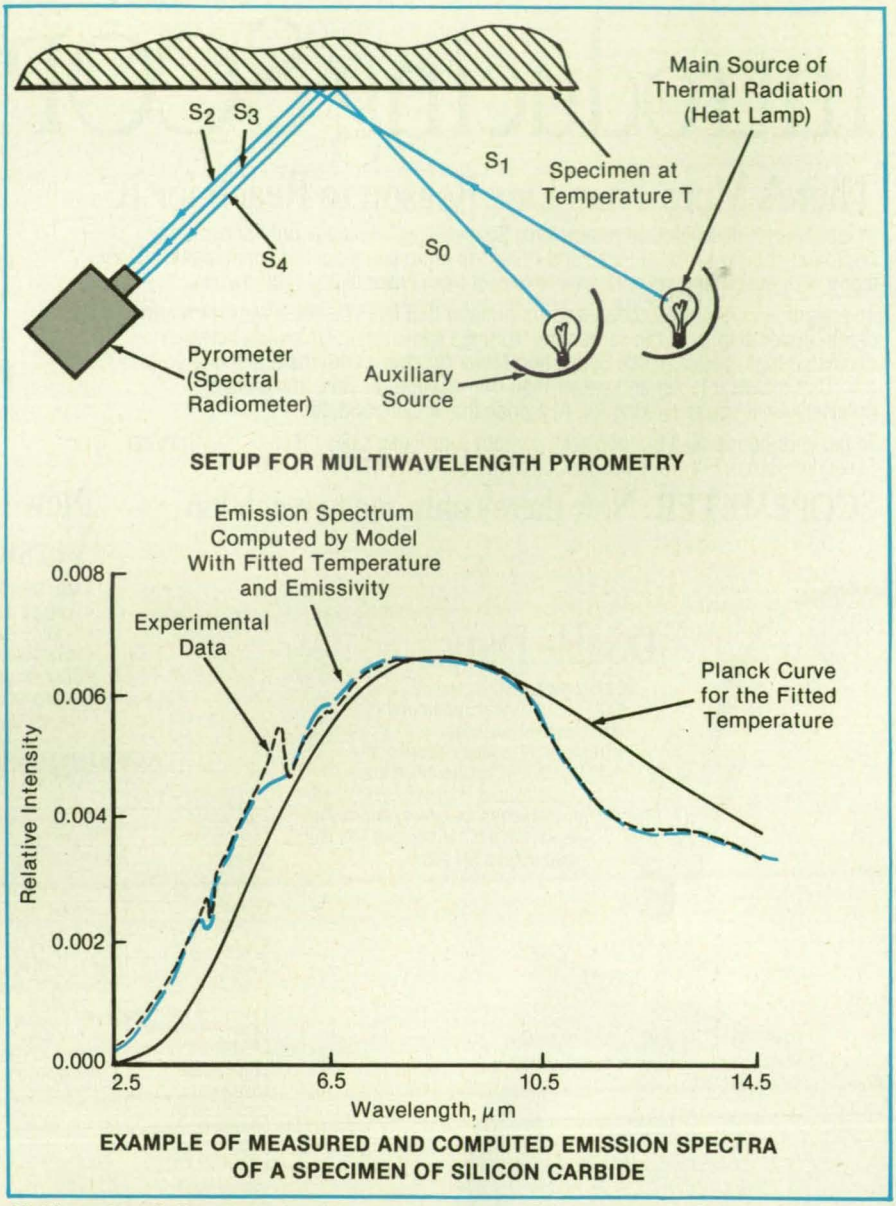
Lewis Research Center, Cleveland, Ohio

Multiwavelength pyrometry is a combination of experimental techniques, theoretical concepts, and data processing that yields more and better information about specimens and the thermal radiation from them than do the older methods of one- and two-color pyrometry. Unlike one-color pyrometry, multiwavelength pyrometry does not require prior knowledge of the emissivity of the specimen. Unlike two-color pyrometry, it does not depend on the assumption that the specimen is gray (that its emissivity is the same at all wavelengths). Unlike both older methods, multiwavelength pyrometry provides corrections for reflections, from the specimen, of thermal radiation emitted by a source other than the specimen: for example, one can correct for reflected radiation that originates at a lamp used to heat the specimen.

The figure schematically illustrates a typical experimental setup for multiwavelength pyrometry. Thermal radiation S_1 from a heat lamp, the spectrum of which is known, impinges on the specimen, and some of it is absorbed, heating the specimen. The heated specimen emits thermal radiation S_2. The part of S_1 that is not absorbed is reflected, thereby adding S_3 to the total radiation coming out of the specimen toward the pyrometer. During some of the measurements, an auxiliary source emits radiation S_0, the spectrum of which is also known. Some of S_0 is reflected, giving rise to S_4. Thus, the total radiation coming out of the specimen toward the pyrometer during these measurements is $S_2+S_3+S_4$.

The pyrometer is a spectral radiometer. It measures the total spectrum $S_2+S_3+S_4$ while the auxiliary source is on; then it measures the total spectrum S_2+S_3 while the auxiliary source is off. The spectrum of S_4 is computed by subtracting the second total spectrum from the first total spectrum. Then the spectral reflectivity of the specimen is computed to within a multiplication constant, f, as the ratio $z(\lambda)$ between the intensities of S_4 and S_0 at each wavelength, λ.

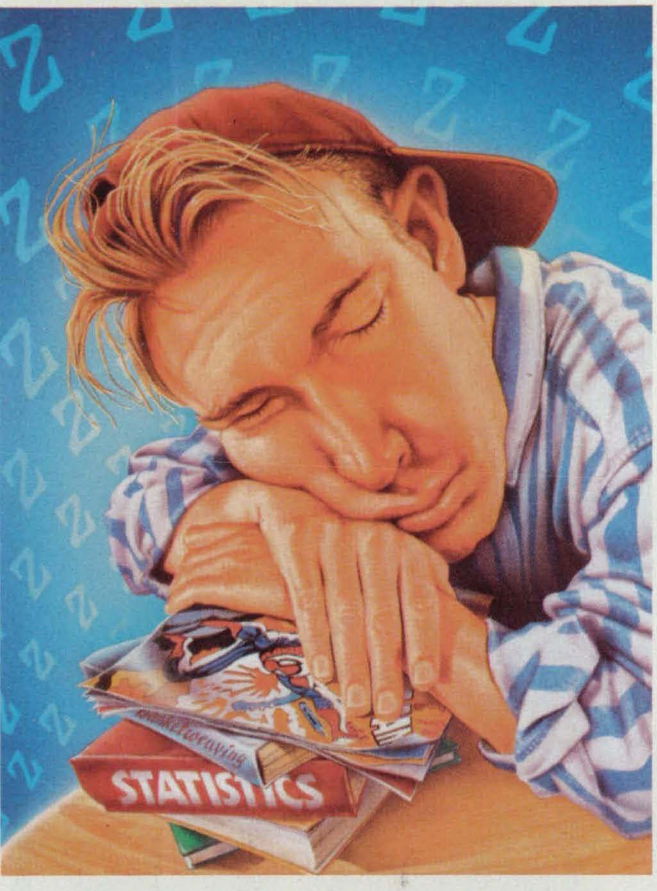
The total radiation S_2+S_3 coming into the pyrometer from the specimen in the absence of the auxiliary source can then be modeled as follows: The spectrum of S_3 is the spectrum of S_1 modified by the spectral reflectivity, $z(\lambda)/f$, of the specimen and multiplied by another constant, g; the spectrum of S_2 is that given by the Planck radiation law for the temperature, T, and the spectral emissivity $\epsilon(\lambda) = 1 - z(\lambda)/f$. A nonlinear least-squares computer program is used to determine the unknowns f, g, and T by searching for a best fit between the measured spectrum and the spectrum computed from the model. The net result is that one has determined not only the temperature but also the spectral reflectivity (and, equivalently, the spectral emissivity) of the specimen.

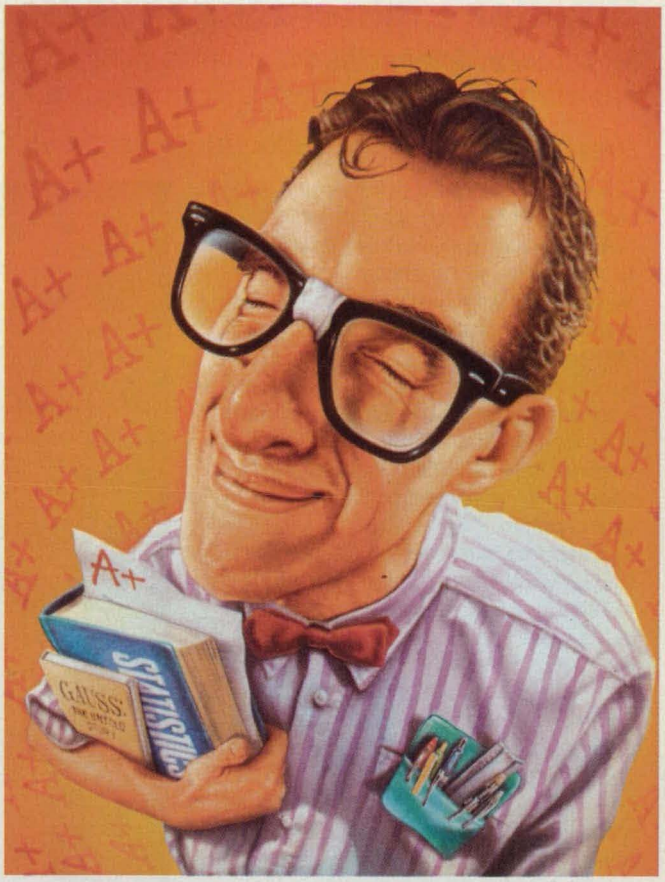


Multiwavelength Pyrometry involves measurements of the spectrum of thermal radiation emitted by and reflected from the specimen. The auxiliary source enables determination of the spectral reflectance of the specimen. The spectral reflectance and temperature of the specimen are obtained from spectral measurements by a nonlinear least-squares curve-fitting routine.

This work was done by Daniel Ng of **Lewis Research Center**. *To obtain a summary of this work, Circle 33 on the TSP Request Card. Further information may be found in*
NASA TM-102578 [N90-23714], "Multiwavelength Pyrometry to Correct for Reflected Radiation,"
NASA TM-10528 [N92-24881], "Multiwavelength Pyrometry for Nongray Bodies," and NASA TM-105286 [N92-19107], "Multiwavelength Pyrometry for Nongray Surfaces in the Presence of Interfering Radiation."

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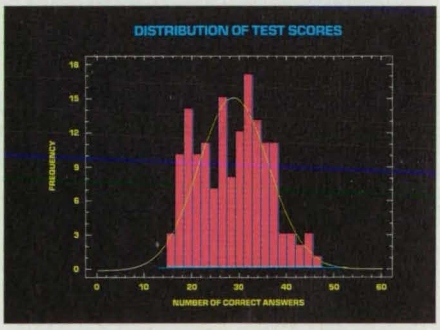


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For More Information Circle No. 399

Smaller, Lighter Magnetic Sector for Mass Spectrometer

Miniaturization enables the development of a portable gas-chromatographic/mass spectrometric apparatus.

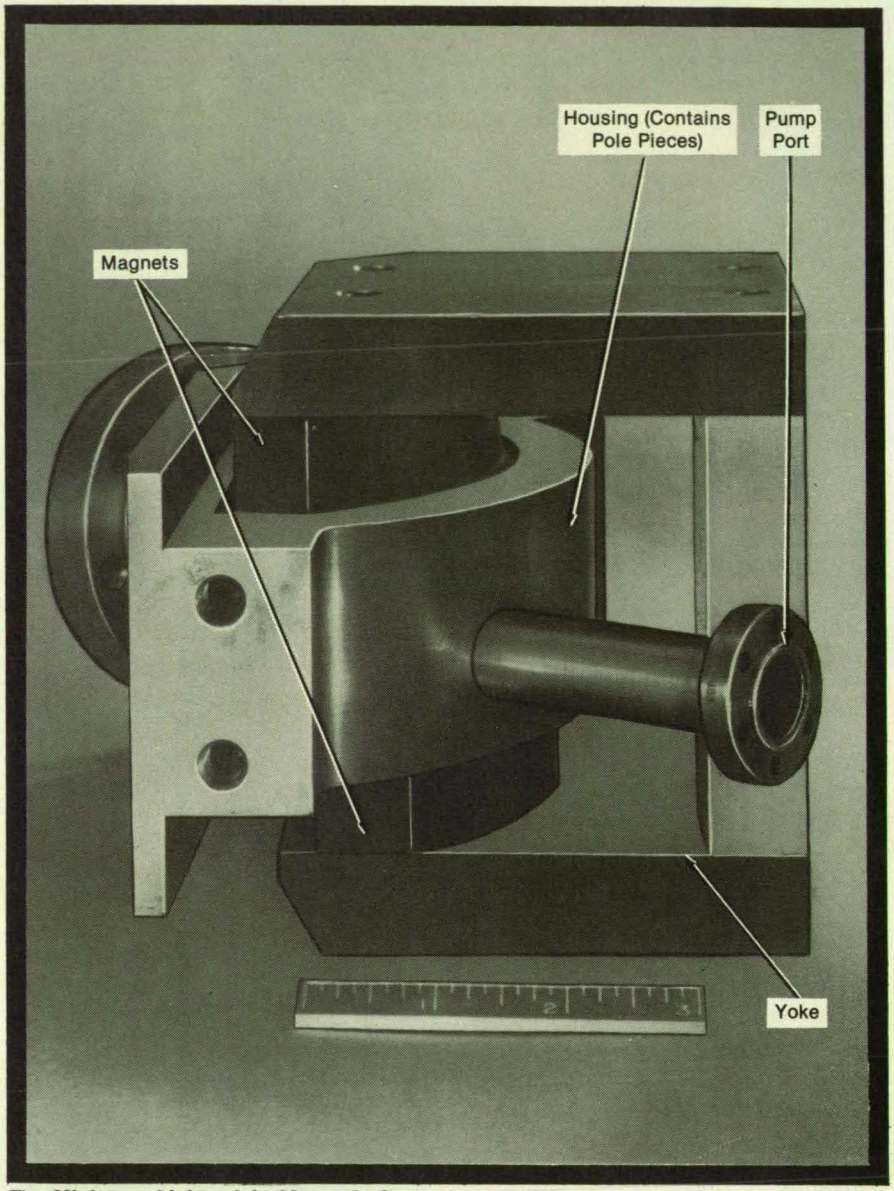
NASA's Jet Propulsion Laboratory, Pasadena, California

A miniature, lightweight focal-plane magnetic sector of a mass spectrometer (Mattauch–Herzog type) has been developed. The magnetic sector shown in the figure makes an integral part of a portable gas-chromatograph/mass spectrometer (GC/MS) being developed at NASA's Jet Propulsion Laboratory. The focal plane covers a nominal range of 40 to 240 atomic mass units for 1-keV ion energy. When fully developed, the GC/MS system would be operable for analyzing pollutants in field environments.

Heretofore, the development of a portable GC/MS system has been hindered by the size, weight, and power consumption of the mass spectrometer and the pumping system necessary to maintain the vacuum. These obstacles have been overcome by using the new miniature magnetic sector for the MS, and a microbore capillary column ($\sim$ 50 μm i.d.) for the GC. The microbore capillary column requires a carrier gas rate of 0.02 to 0.05 atm cm^3 min^{-1}, which is 50 to 100 times less than the flow rate used in a commercial GC. The low flow rate reduces the size, weight, and power of the required pumping system.

However, the peaks emerging from a microbore GC column are narrow and closely spaced, necessitating a high rate of mass-spectrometer data acquisition. A scanning mass spectrometer commonly used in a GC/MS instrument, is limited in speed for the measurement of such GC peaks. A mass spectrograph (nonscanning) because of its simultaneous measurement of ion intensities of all masses, can obtain mass spectra from such narrow and closely spaced GC peaks. In addition, a mass spectrograph possesses a 100-percent duty cycle for signal measurement and, therefore, has a lower detection limit for the analyte compared to that of a scanning MS, which measures <1 percent of the ion signal. Although eminently suited for direct combination with a microbore column, focal plane mass spectrometers are generally heavier due to the weight of the magnet assembly, i.e., magnet, yoke, and the pole pieces. For the development of a portable GC/MS, the magnetic sector assembly has been miniaturized and its weight reduced by utilizing efficient magnet and yoke materials and by making improvements in its design.

The miniature, lightweight magnetic sector weighs <10 kg, about 2/5 that of an earlier design utilizing Alnico 5-VII for magnet and cold-rolled steel for yoke materials. The magnetic components were made lighter and smaller by use of two advanced materials. The permanent magnet was fabricated from a high-energy product (maximum 35 MG•Oe) Nd/B/Fe alloy. The mass of a comparable magnet made of Alnico 5-VII would be 2.3 times that of the new magnet. The yoke material, a V/Co/Fe alloy, possesses higher permeability (2kG/Oe at a magnetomotive force of 10 Oe) than cold-rolled steel (1.25 kG/Oe) used previously. The pole pieces were tapered sharply to reduce their mass and increase the magnetic field strength in the magnet gap. The combined use of the new magnet and the yoke material, along with the design changes in the pole pieces, reduced the size and mass of the magnet assembly and, consequently, that of the overall focal plane mass spectrometer. This, in conjunction with the reduced pumping requirement due to the use of the microbore GC column, has demonstrated the practicality of a high performance portable GC/MS instrument.

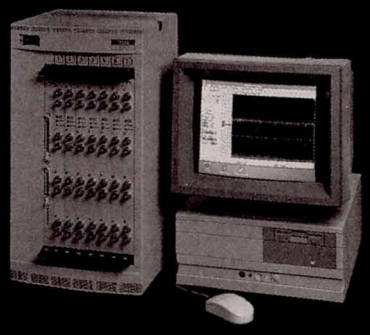


The **Miniature, Lightweight Magnetic Sector** is part of the prototype of a new generation of portable GC/MS instruments. The scale is in inches.

This work was done by Mahadeva P. Sinha of Caltech and Albert D. Tomassian of Rockwell International Corp. for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 27 on the TSP Request Card.*

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For More Information Circle No. 526

Device for Perception of Polarization

A polarized image viewed through a rotating polarizing filter appears to pulsate.

Lyndon B. Johnson Space Center, Houston, Texas

An optical device enables a human observer to perceive the polarization of light. The device can be used alone for viewing in real time and/or in conjunction with a video or movie camera to record for subsequent detailed quantitative analysis of polarization in the scene. The device can be used in remote sensing to classify portions of scenes according to polarization characteristics, to enhance viewing through the atmosphere and oceans, and to enhance contrasts. It has been used to monitor an oilspill from the air and might be used to detect changes in soil moisture and to map wetlands, among many other possible civilian and military applications.

The polarization-perception device (see figure) consists of a polarizing filter, a drive mechanism that rotates the filter, a power supply, and a mount. The rotation of the filter causes the brightness of an image in polarized light to pulsate. The device can be used in conjunction with spectral filters to isolate bands of the spectrum of interest to specific disciplines.

When the device is used in synchronism with a recording video or film camera, one can subsequently determine the angle of the polarization by correlating the phase of the fluctuation with the angle of the polarization axis in the rotating filter. The accuracy of this correlation is a function of the speed of rotation of the polarizing filter. For this and other scientific purposes, the fluctuating images can be digitized and processed in an objective manner.

This work was done by Victor S. Whitehead of **Johnson Space Center** *and Kinsel Coulson. For further information, Circle 49 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center [see page 20]. Refer to MSC-21915.



This **Polarization-Perception Device** enables an observer to identify surfaces that reflect polarized light.

Electromechanical Apparatus Measures Residual Stress

A nondestructive test exploits the relationship between stress and eddy-current-probe resistance.

Goddard Space Flight Center, Greenbelt, Maryland

The apparatus shown schematically in Figure 1 yields data on the residual stress or strain in a metal tension/compression specimen (the stress or strain that remains in the specimen when no stress is applied from without). The apparatus is an assembly of commercial equipment: a tension-or-compression testing machine, an eddy-current probe, an impedance gain-and-phase analyzer that measures the impedance of the probe coil, and a desktop computer, which controls the other equipment and processes the data that it receives from the impedance gain-and-phase analyzer.

The apparatus is used to perform a nondestructive test based on the discovery that when an eddy-current probe is excited at a suitable frequency and placed on a metal specimen that is being stretched or squeezed, the electrical resistance and reactance of the probe coil increase monotonically with the magnitude (regardless of direction) of the total (residual + applied) stress in the specimen. To determine the residual stress, it is necessary to measure the impedance of the probe coil over a range of applied tensile and compressive stresses that include at least the point of zero applied stress and the applied stress at which the resistance of the probe coil is a minimum.

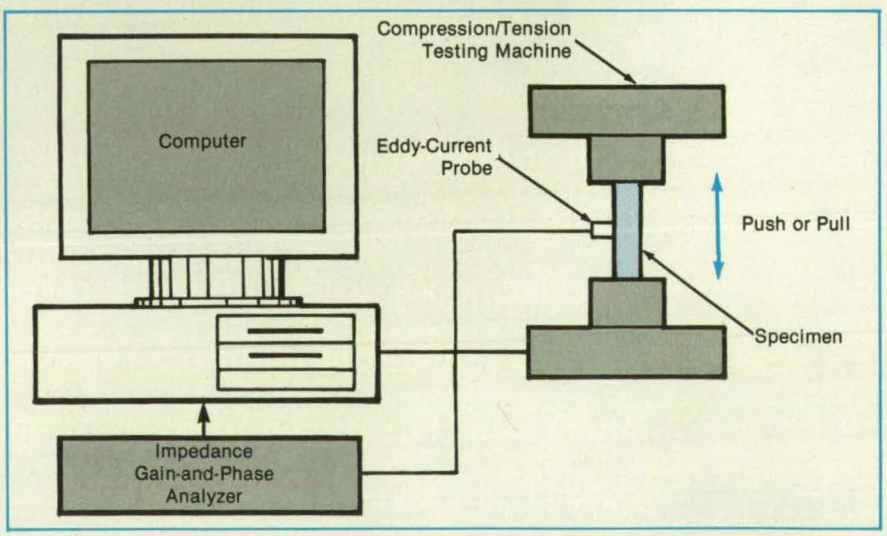


Figure 1. The **Resistance of the Eddy-Current-Probe Coil** is measured as a function of the tension or compression applied to the specimen by the testing machine.

The interpretation of the data from a test is straightforward, as shown in Figure 2 for a nickel-200 specimen. If the minimum resistance does not occur at the point of zero applied stress, then there must be residual stress in the specimen. The minimum resistance occurs at the applied stress that cancels the residual stress. In this case, the minimum resistance occurs at an applied tensile stress of 0.07×10^{-3}. Thus, the residual stress in the nickel-200 specimen is a compressional stress of 13.2 MPa based on the stress–strain curve of nickel-200.

This work was done by Engmin J. Chern and Yury Flom of **Goddard Space Flight Center.** *For further information, Circle 29 on the TSP Request Card.*



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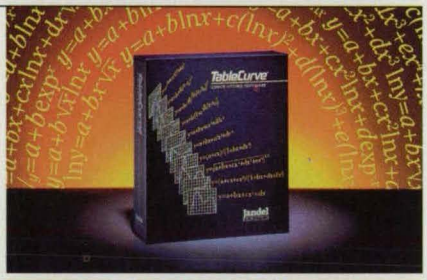


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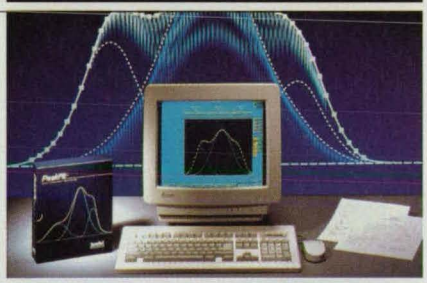


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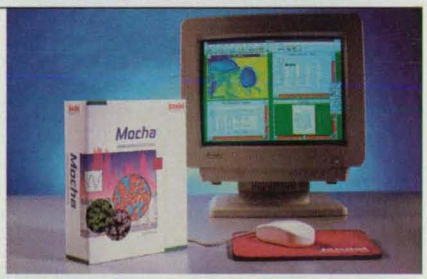
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This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Goddard Space Flight Center [see page 20]. Refer to GSC-13451.

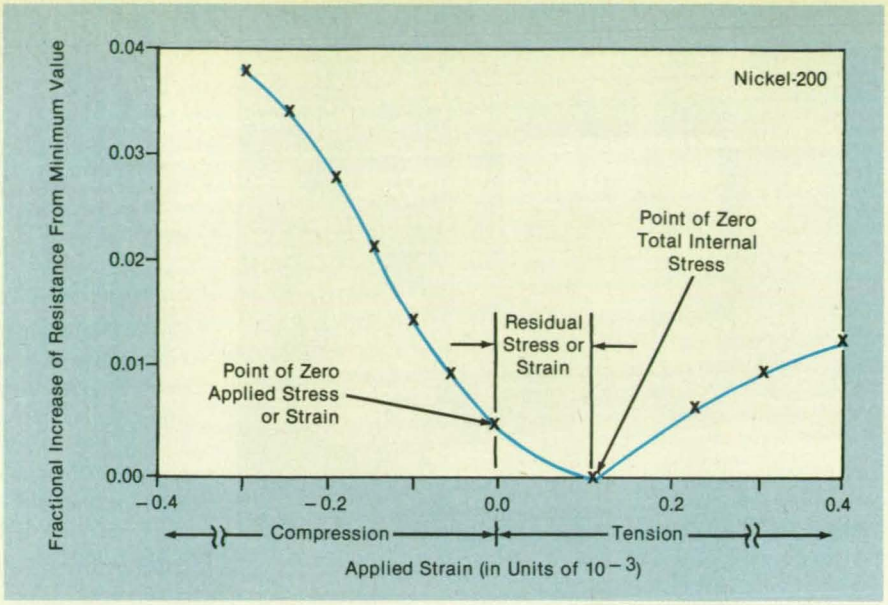


Figure 2. These normalized **Resistance-vs.-Stress Data** were acquired by testing a specimen of nickel in an apparatus like that of Figure 1.

Noninvasive Optical Probe of Ferroelectric Films

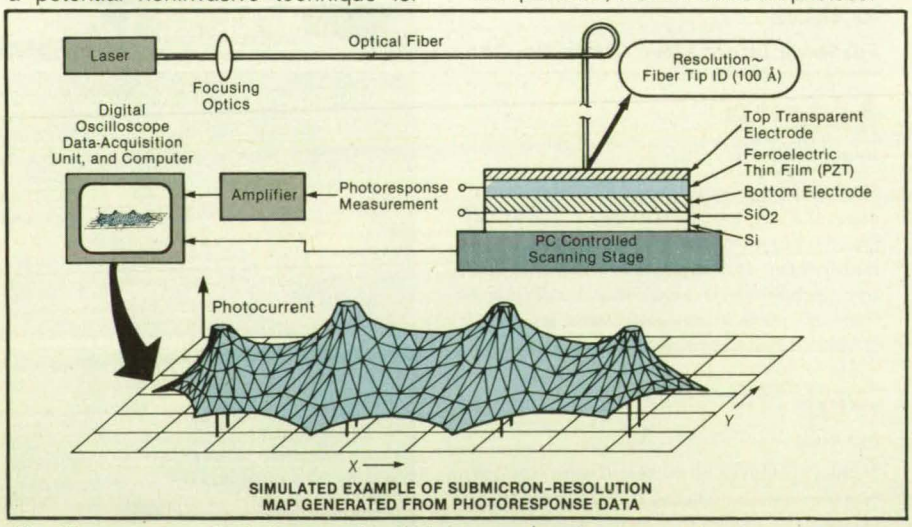
This nondestructive diagnostic technique would yield high-spatial-resolution information on the distribution of polarization domains.

NASA's Jet Propulsion Laboratory, Pasadena, California

Thin films of ferroelectric materials (e.g., lead zirconate titanate) would be probed by a near-field, noninvasive mapping of the photoresponse from the film to obtain high-spatial-resolution information on the distribution of polarization domains within the film. Thin films of ferroelectric materials are leading candidates for use in nonvolatile electronic memories. At present, to obtain information regarding the polarization-domain distribution, the specimens of these materials are examined by transmission electron microscopy (TEM). This TEM study involves destructive sample-preparation techniques that may perturb the ferroelectric properties, thereby leading to distorted evaluations. The near-field photoresponse-mapping technique proposed herein offers a potential noninvasive technique for evaluation of the films to study the polarization domains at a submicron resolution level.

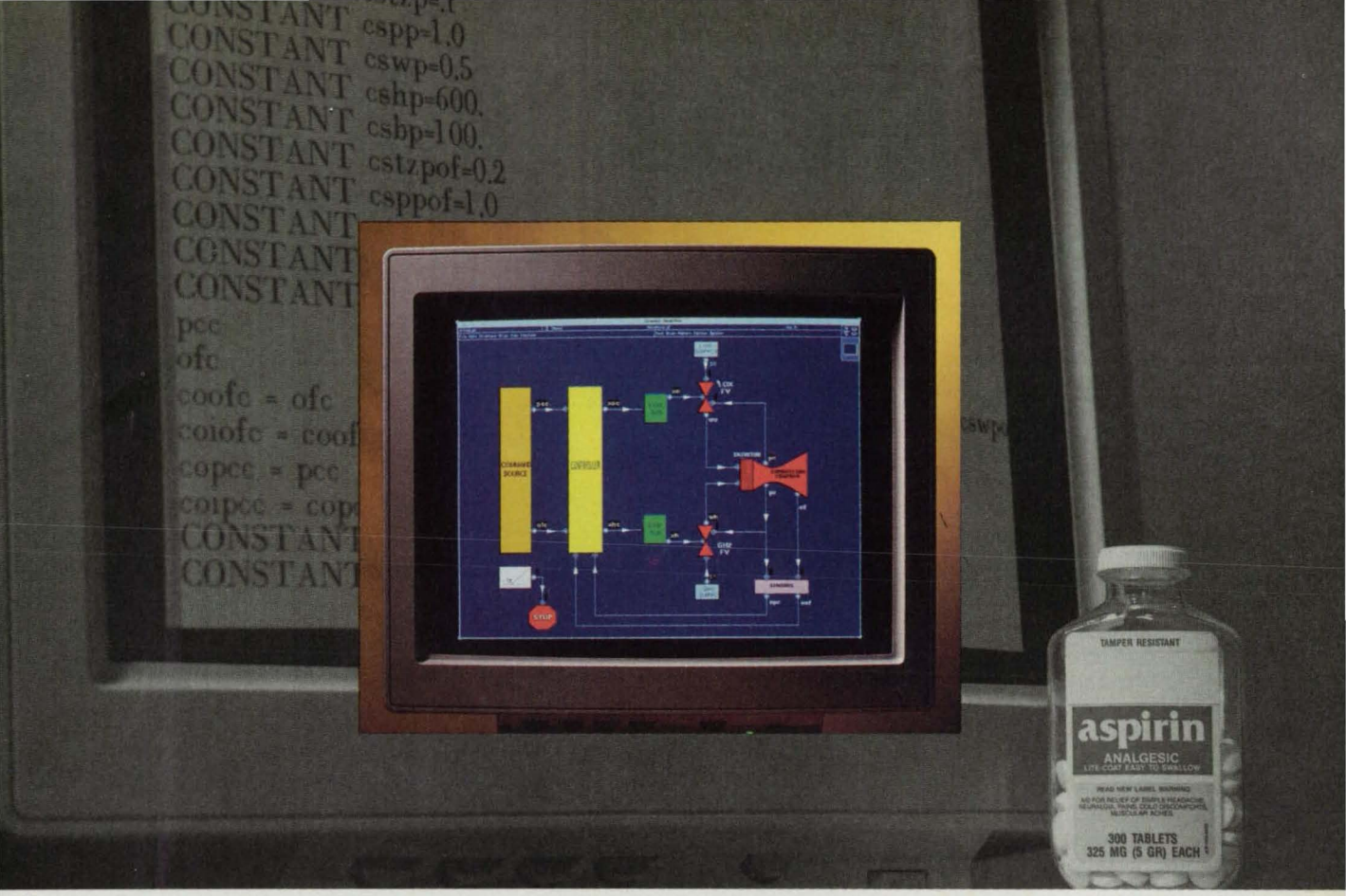
When a ferroelectric material is illuminated with photons, two broad classes of mechanisms could be triggered, depending on the wavelength of the photon, intensity of illumination, and the device configuration utilized. These are the photocarrier-generated electronic effects such as photovoltaic, photoconductive, localized electronic transitions or space-charge effects; and the thermally triggered pyroelectric or piezoelectric effects. If the illumination wavelength is more energetic than the gap between the valence and conduction electron energy bands (the bandgap of the material) and not intense enough to heat the specimen, then the transient photocurrent at the onset of the illumination is primarily due to the space-charge effects. However, if the incident beam is intense enough to heat the specimen locally and is also at a wavelength less energetic than the bandgap, then predominantly the pyroelectric/piezoelectric-current response is observed. This response is distinctly polarization-direction-dependent and can serve as an indicator of internal polarization distribution across the film if a localized beam spot can be used. Thereby, such photon-beam-induced current is conceived as a noninvasive diagnostic tool for evaluating ferroelectric thin films at the submicron resolution level in terms of their polarization-domain distribution. To achieve the submicron resolution, the near-field illumination from a localized optical probe such as the subwavelength aperture of an optical fiber (inner diameter ≤100 Å) could be utilized.

The specimen would be mounted on a translation stage, which would operate under computer control to scan the submicron spot of light across the surface of the specimen (see figure). The photoresponse of the specimen would be recorded as the function of the position. The photocurrent-versus-position data would then be deconvolved from the applicable point-spread or instrument-response function to obtain a submicron-level map of the internal distribution of the polarization domains in the ferroelectric thin film.



The **Photoresponse Technique** would yield data on the microscopic structure of electric fields in that ferroelectric material, without disturbing the structure.

This work was done by Sarita Thakoor of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 18 on the TSP Request Card.*
NPO-18549



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Self-Amplified Optical Pattern Recognizer

The recognition signal is amplified within a photorefractive filter.

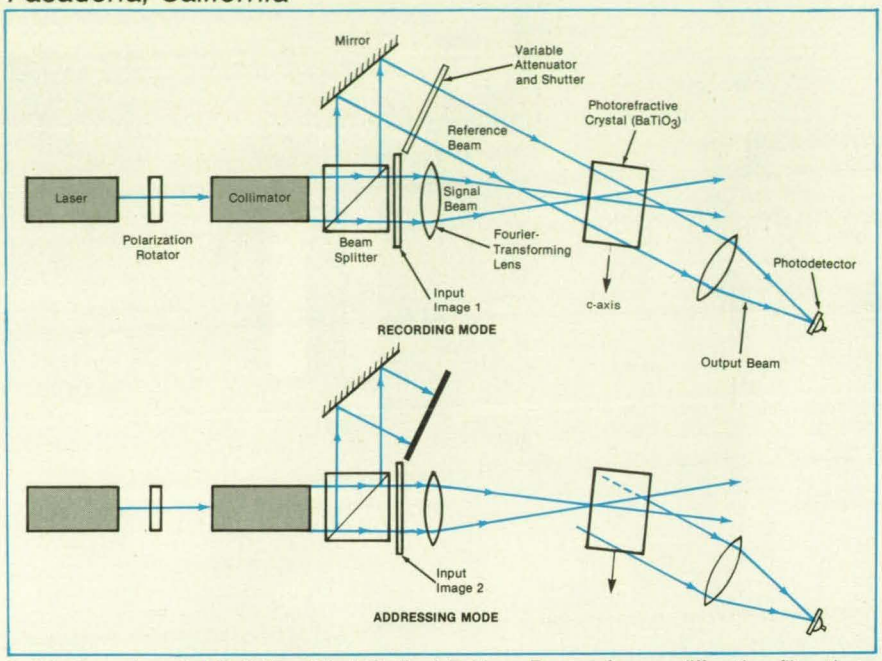
NASA's Jet Propulsion Laboratory, Pasadena, California

Self-amplified optical pattern recognizers are being developed for use in recognition of patterns, in optical computing, and in optoelectronic neural networks. In a self-amplified optical pattern recognizer, a photorefractive crystal (one that exhibits a nonlinear electro-optical effect) serves as the medium in which one holographically records the diffraction-grating filter that represents the pattern with which recognition is sought. The apparatus is said to be "self-amplified" because the signal is amplified within the filter to many orders of magnitude greater than in prior optical pattern recognizers.

The figure illustrates schematically an experimental self-amplifying optical pattern recognizer. A collimated beam of suitable polarization is split into a signal beam and a reference beam. The signal beam passes through a transparency that contains the image in question. A lens then focuses this beam onto a spot on the face of a crystal of $BaTiO_3$ (which is photorefractive), thereby forming Fraunhofer diffraction of the image.

In the recording mode, a reference beam strikes the photorefractor crystal at an angle different from that of the signal beam, thereby photorefractively forming the complicated holographic diffraction-grating filter that represents the image. The geometrical and optical parameters of the apparatus in the recording mode are chosen so that in subsequent operation in the addressing mode, optical energy will be coupled strongly (if there is a recognition) from the signal beam to the output recognition-indicating beam via two-wave mixing.

In the addressing mode, the reference beam is blocked, and the signal beam passes through an image that may or may not be the same as the one represented in the filter. The strength of the output signal is then indicative of the degree of similarity between the two images.



In this **Experimental Self-Amplified Optical Pattern Recognizer,** a diffraction filter that represents input image 1, with which recognition is sought, is recorded holographically in a $BaTiO_3$ crystal. The degree of similarity between input images 1 and 2 is then indicated by the amount of light transferred from the signal beam to the output beam by two-wave mixing in the crystal.

Because of the amplification available, an apparatus of this kind can be made sensitive to very weak signals, and the conceptual design can be extended to include many channels with the same laser input power. An advanced compact optical pattern recognizer might include many channels fed by microlasers. Various response times, sensitivities, wavelengths, and spatial frequencies can be selected by appropriate choices of photorefractive materials and parameters of two-wave-mixing schemes. Spatial light modulators (e.g., microchannel-plate and liquid-crystal television devices) could be incorporated to provide for rapid updating of filters. The basic principle of operation is applicable to many types of correlation filters, including (but not limited to) Vander Lugt matched filters, joint-transform filters, and phase-only filters.

This work was done by Hua-Kuang Liu of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 101 on the TSP Request Card.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

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Refer to NPO-18009, volume and number of this NASA Tech Briefs *issue, and the page number.*

Apparatus Measures Seebeck Coefficient and Resistivity

Electrical measurements are made by four point probes, two of which double as temperature probes.

NASA's Jet Propulsion Laboratory, Pasadena, California

A laboratory apparatus measures both the Seebeck coefficients and the electrical resistivities of candidate thermoelectric materials at temperatures from ambient to 1,300 K. Heretofore, the Seebeck and resistivity measurements were taken in separate apparatuses. But some candidate materials — especially Si/Ge alloys — are subject to precipitation of dopants at high temperatures, with consequent hysteretic distortion of the two thermoelectric measurements. This apparatus makes it possible to take both measurements alternately and in rapid succession during the same heating cycle, thereby reducing the distortion.

The apparatus includes a furnace, which heats a rod sample of thermoelectric material to the prescribed measurement temperature. Two fused-quartz light pipes of ½-in. (13-mm) diameter are spring-loaded against the ends of the sample and thus hold the sample in place (see figure). Thermal radiation from two lamps outside the furnace is coupled via the light pipes to the ends of the specimen. By turning on one lamp or by applying more power to one lamp than to the other, one creates

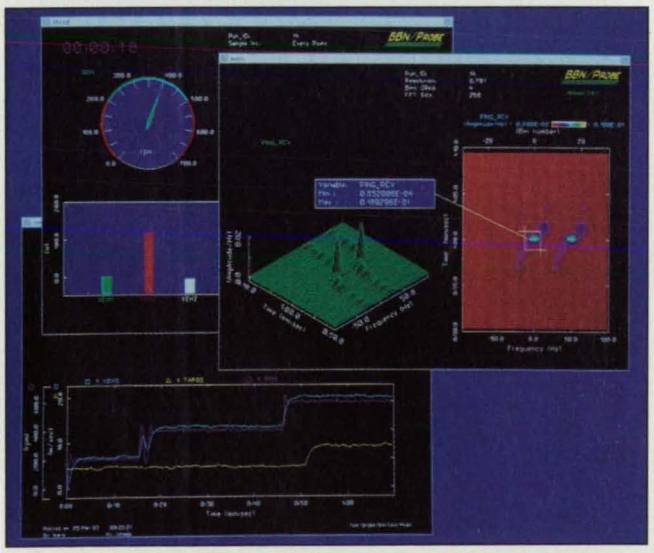
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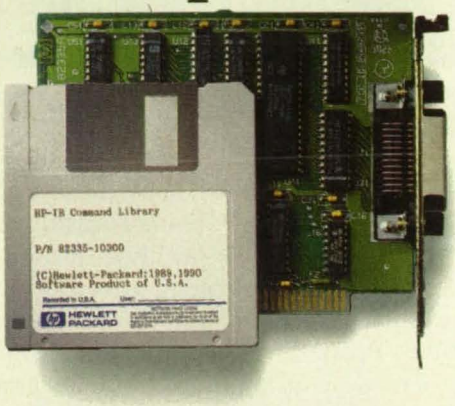
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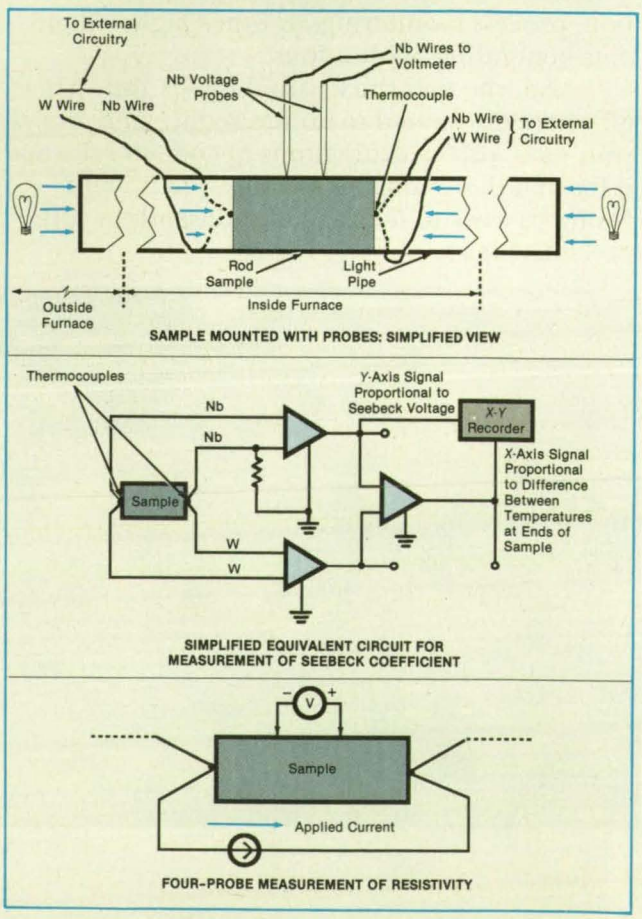
a longitudinal gradient of temperature in the specimen for use in measuring the Seebeck coefficient:

$$\text{Seebeck coefficient} = \frac{\text{open-circuit voltage between ends of sample}}{\text{difference between temperatures at ends of sample}}$$

Nb and W wires are joined into thermocouples, one of which is embedded in the end of each light pipe, with the Nb in contact with the sample. (The thermocouples are shielded from the radiation in the light pipe.) Because the Seebeck voltage of Nb is negligible, the Nb wires can be regarded as providing direct access to the Seebeck voltage between the ends of the sample. Simultaneously, the Seebeck voltage of the Nb/W thermocouple combinations are directly indicative of the temperatures at the ends of the sample. These measurements are extracted by means of the differential-amplifier network shown in the middle of the figure.

The electrical resistivity is measured straightforwardly by a four-probe method. For this purpose, two point-contact voltage probes are pressed against the side of the sample, separated lengthwise by 0.25 in. (6.35 mm). The voltage between these probes is measured while a current of 100 to 200 mA is applied to the sample via the end thermocouple (point) contacts. The electrical resistance and resistivity of the sample are then calculated in the usual way from the ratio between the voltage and current, with a correction factor that accounts for the effect of the point-contact configuration on the distribution of electric potential and current in the specimen. In this calculation, the voltage reading might also have to be corrected for a small Seebeck voltage generated by a small residual gradient of temperature along the sample.

This work was done by Leslie D. Zoltan, Charles Wood, Jean-Pierre Fleurial, and Yixin Liu of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 91 on the TSP Request Card. NPO-18422.*



The **Sample Is Probed at Four Points:** The end probes yield measurements of Seebeck voltage and temperature difference and serve as current contacts for resistivity measurements. The side probes yield voltage for the resistivity measurements.

Probe for Measuring Dynamic Gas Temperature in Reversing Flows

The temperature of the gas can be deduced from outputs of three thermocouples.

Lewis Research Center, Cleveland, Ohio

In a proposed technique for determining the time-varying temperature of a flowing gas, the raw measurements of three thermocouples of different sizes would be processed by relatively simple data-reduction software. The three-thermocouple technique was conceived to overcome an important limitation of the single-thermocouple technique; namely, that it cannot yield an accurate value of temperature in a reversing flow because (1) unless the characteristic time for the transfer of heat between the thermocouple and the gas remains constant at a known value, there is no way to infer the temperature of the gas if the thermocouple reading varies with time, (2) this characteristic time varies significantly in the neighborhood of zero velocity, and (3) velocity goes to zero in reversing flow.

The characteristic time is not assumed to be constant in the proposed technique. Instead, the reciprocal of the characteristic time is calculated by use of a Nusselt-number heat-transfer equation in which the Nusselt number is assumed to equal a constant plus a term proportional to the square root of the Reynolds number based on the diameter of the thermocouple. When the equation for the Reynolds number (including the terms that express the effects of velocity and the properties of the gas) is inserted in the equation for the Nusselt number and the equation for the Nusselt number is inserted in the equation for the rate of heating of the ith thermocouple, the resulting equation is

$$D_i^2 \frac{dT_i}{dt} = \left(a + b\sqrt{D_i}\right)\left(T_g - T_i\right)$$

where D_i = the diameter of the ith thermocouple, T_i = the temperature reading of the ith thermocouple, T_g = the temperature of the gas (which one is seeking to determine), t = time, a is a constant that depends on the properties of the gas, and b is a variable that depends on the velocity and the properties of the gas.

It turns out not to matter that b is variable and to make no difference whether a is constant or variable, because by applying the foregoing equation to the three thermocouples and taking appropriate sums and differences, one can eliminate a and b. The resulting equation is

$$D_1^2 \frac{dT_1}{dt}\left(\sqrt{D_2} - \sqrt{D_3}\right)\left(T_g - T_1\right) + D_2^2 \frac{dT_2}{dt}\left(\sqrt{D_3} - \sqrt{D_1}\right)\left(T_g - T_2\right) + D_3^2 \frac{dT_3}{dt}\left(\sqrt{D_1} - \sqrt{D_2}\right)\left(T_g - T_3\right) = 0$$

This is equivalent to a quadratic equation for T_g. The other quantities in the equation are the known diameters, the known readings, and the known rates of change of the readings of the thermocouples. The solution to this equation is easily implemented in a computer program; if the sampling rate is high enough and the computer fast enough, it can give a current indication of the fluctuating T_g.

This work was done by Gustave C. Fralick of **Lewis Research Center**. *For further information, Circle 5 on the TSP Request Card. LEW-15087*

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Measuring Highly Elliptical Orbits Using the GPS

A combination of Doppler and GPS measurements would provide the required accuracy.

A report discusses the precise determination of highly elliptical orbits of spacecraft around the Earth, by use of one of the following techniques: (1) conventional two-way Doppler tracking of the spacecraft from ground stations, (2) conventional two-way Doppler tracking from ground stations augmented by tropospheric-delay calibrations obtained at the ground stations by simultaneous tracking of the navigation satellites of the Global Positioning System (GPS), or (3) the method of item 2 augmented further by GPS tracking from a GPS flight instrument aboard the spacecraft.

The analysis in this report applies especially to scientific satellites that would carry radio telescopes. The highly elliptical orbits would extend the baselines available for very-long-baseline interferometry (VLBI) to lengths greater than the maximum of about 12,000 miles (19,000 km) available between stations on Earth. For example, one contemplated orbit of the International VLBI Satellite (IVS) would reach a maximum altitude of 150,000 km (with a minimum altitude of 5,000 km). These elliptical orbits are difficult to determine precisely because the viewing geometrics and dynamics can vary considerably with altitude. The position, velocity, and acceleration of the spacecraft must be determined accurately enough to enable correlation of the radio-telescope observations with those of other station(s) in the VLBI network that observe the same astronomical object at the same time.

The accuracies available from the three orbit-determination techniques were analyzed as applied to two spacecraft: (1) the MUSES-B satellite of the Japanese VLBI Space Observatory Program (VSOP), to be launched the year 1995 into an orbit between a minimum altitude of 1,000 km and a maximum altitude of 20,000 km; and (2) the IVS mentioned previously, to be launched in the late 1990's. In both cases, it was assumed that the satellites would be equipped with antennas capable of viewing GPS satellites in almost any direction.

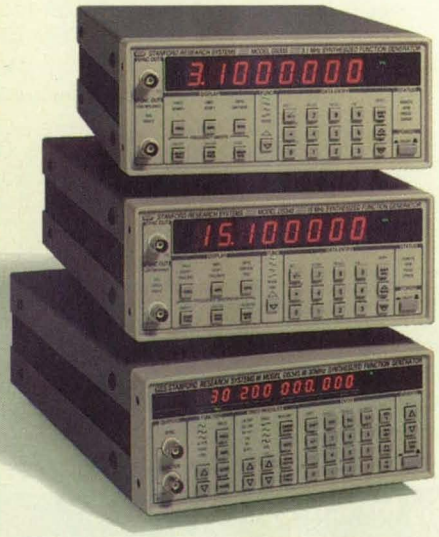
In the VSOP case, the results of the analysis show that the required positional accuracy of 130 m could be attained easily by use of two-way Doppler tracking primarily. The required velocity accuracy of 0.4 cm/s could be attained by two-way Doppler tracking augmented by the GPS tropospheric-delay calibrations and precise coordinates of ground stations. Further augmentation with a GPS tracking instrument aboard the satellite would yield position and velocity accuracy beyond the basic scientific requirements upon the VSOP mission.

In the IVS case, the results of the analysis show that the combination of GPS-augmented Doppler tracking and GPS tracking from aboard the satellite would be necessary to attain the required positional accuracy of 30 cm at altitudes from 5,000 to 75,000 km. At altitudes from 75,000 to 150,000 km, the accuracy could deteriorate to about 1 m.

This work was done by Stephen M. Lichten and Jeffrey A. Estefan of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information may be found in AIAA paper A90-53027, "High-Precision Orbit Determination for High-Earth Elliptical Orbiters Using the Global Positioning System."*

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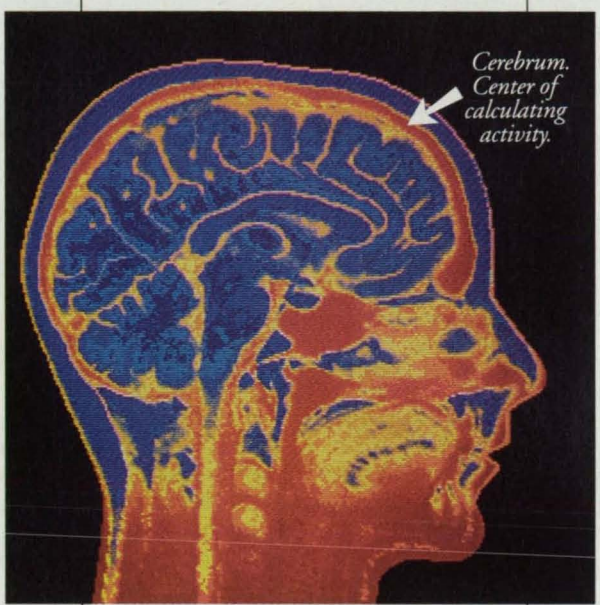
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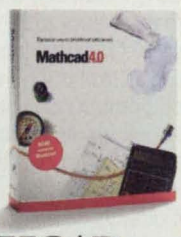
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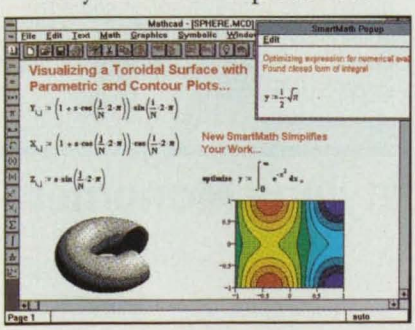
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For More Information Circle No. 688

Synthesizing Diacetylenes With Nonlinear Optical Properties

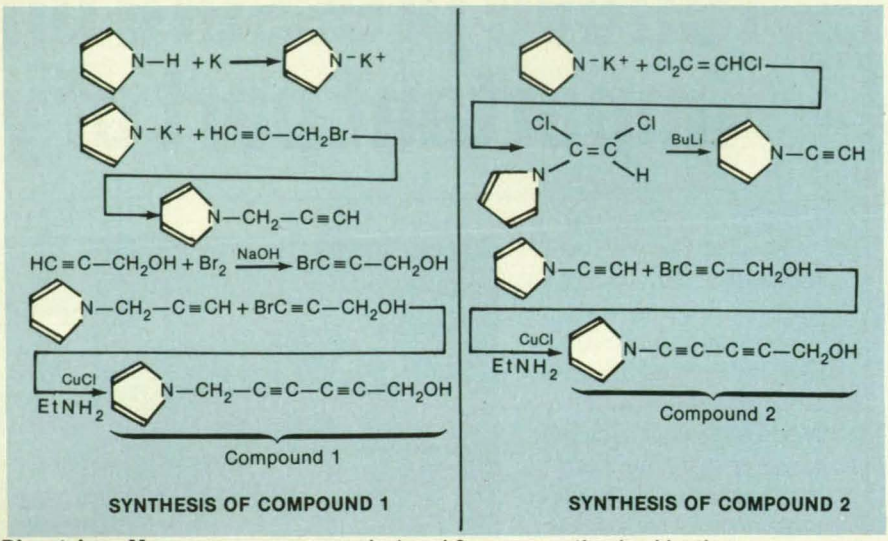
Investigations of synthesis, deposition, and polymerization are continuing.

Marshall Space Flight Center, Alabama

Diacetylene compounds are being investigated to determine whether they have the nonlinear optical properties that would make them useful for four-wave mixing, generation of third harmonics, phase conjugation, and the like. The diacetylene labeled in the figure as compound 1 has been synthesized and then polymerized both in the solid state and in the liquid state. The observed chemical and optical properties of this and other diacetylenes will provide a test of the accuracy of semiempirical molecular-orbital mathematical models that have been used to predict their chemical and optical properties. For example, the mathematical models predict that the properties of compound 1 will be quite different from those of compound 2, which has also been synthesized and will be subjected to experiments like those performed on compound 1.

Compounds 1 and 2 were synthesized as shown in the figure, then purified by column chromatography using silica gel as the support and benzene as the eluent. Even purified samples of these monomers contained small amounts of the corresponding polymers, which imparted a red-brown color.

Pure crystals of the compound 1 can be grown as thin films on a glass or quartz condenser that has a temperature of −20 °C from a vapor that has a temperature of 30 to 35 °C and a pressure of 0.02 mm Hg (3 Pa). (Although the freezing temperature of compound 1 is about 5 °C, it has a strong tendency to undercool; therefore a temperature much lower than the freezing temperature is necessary to condense it directly from vapor to solid.) Compound 1 has also been condensed initially as a liquid (at −10 °C) and then allowed to freeze slowly overnight to see how the crystalline quality of a film grown this way compares with that of a film grown directly as a solid.



Diacetylene Monomers —compounds 1 and 2 — are synthesized by these sequences of chemical reactions. The monomers can be polymerized by ultraviolet light, forming potentially useful nonlinear optical materials.

The frozen or liquid monomer 1 is polymerized by exposure to long-wavelength (365-nm) ultraviolet radiation for about 3 to 4 days, during which time the monomer is kept below or at the freezing temperature, respectively. During this process, the initially colorless solid monomer film turns into a red-brown polymer film, which remains solid when warmed to room temperature. The optical properties of the film can then be measured.

Polymerization in the liquid state may eliminate two potential disadvantages of polymerization in the solid state. Firstly, in the solid state, grain boundaries and other crystalline imperfections in the monomer film can degrade the optical properties of the polymer film produced. Secondly, the crystalline packing of the monomer must be such that the triple bonds of neighboring diacetylene molecules are in the correct proximity for polymerization to take place; not all diacetylenes satisfy this requirement. In contrast, in the liquid state, there are no crystalline defects, and, because the molecules are free to move about, it is easier for the bonds to line up in the correct manner for polymerization to occur. Hence, polymerization of diacetylenes in the liquid state may, in certain cases, have some advantages over polymerization in the solid state.

This work was done by Samuel P. McManus, Donald P. Frazier, and Mark S. Paley of Universities Space Research Association for **Marshall Space Flight Center**. *For further information, Circle 6 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 20]. Refer to MFS-26186.

Films Containing Optically Nonlinear Diacetylene Monomer

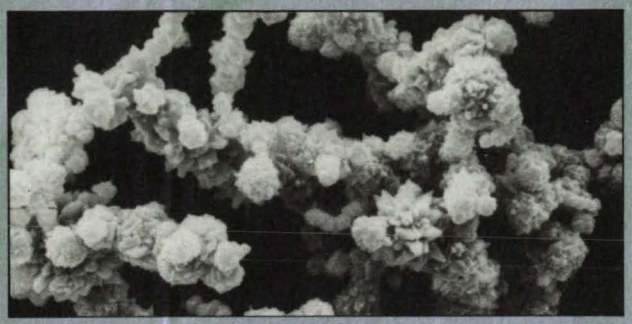
Pronounced nonlinear optical properties show promise for applications in communication and computation.

Marshall Space Flight Center, Alabama

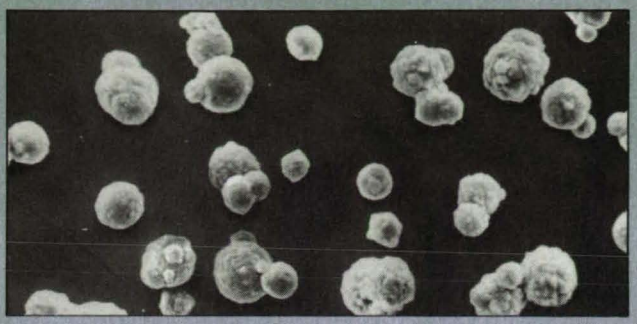
Solid films that exhibit nonlinear optical properties have been prepared as mixtures of poly(methyl methacrylate) with various amounts of the diacetylene monomer called "compound 1" in the preceding article, "Synthesizing Diacetylenes With Nonlinear Optical Properties" (MFS-26186). Films of this type might be useful as phase-conjugate mirrors in laser-beam communications and as optical switches in optical computers.

This particular diacetylene monomer ex-

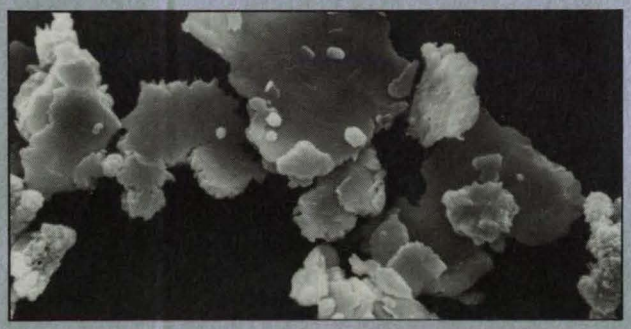
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For More Information Circle No. 652

hibits strong third-order nonlinear optical properties, both in pure form and in solution. Like many useful monomers, it is liquid at room temperature, but films that are solid at room temperature are needed in practical applications. Although the monomer can be polymerized to obtain a solid film, experiments have shown that the polymer does not exhibit the strong nonlinear optical properties of the monomer from which it is made.

Therefore, it was conjectured that to impart the desired strong nonlinear optical properties to a solid film, it is necessary to incorporate the diacetylene monomer into the film by mixing it, but not polymerizing it, with a different polymer. Mixtures were prepared by dissolving various amounts of the diacetylene monomer into a solution of poly(methyl methacrylate) in acetone. Films were made by casting the solution onto quartz slides, then allowing the solvent to evaporate.

The films were exposed to light from an argon-ion laser. Like the monomer in solution, they exhibited self-phase modulation, self-focusing and -defocusing, phase conjugation, and strong dependence of the index of refraction upon intensity of light. The optical properties of a film can be tailored for a particular application by choice of the concentration of monomer and thickness. Uniform films with thicknesses of a few micrometers, which could serve as optical waveguides, can be solution-cast by spin-coating poly(methyl methacrylate)/diacetylene monomer solutions onto quartz disks.

This work was done by Mark S. Paley, Samuel P. McManus, and Donald O. Frazier of Universities Space Research Association for **Marshall Space Flight Center**. *For further information, Circle 9 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 20]. Refer to MFS-26187.

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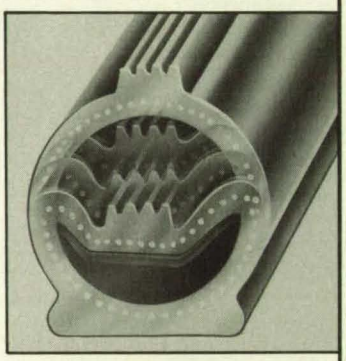
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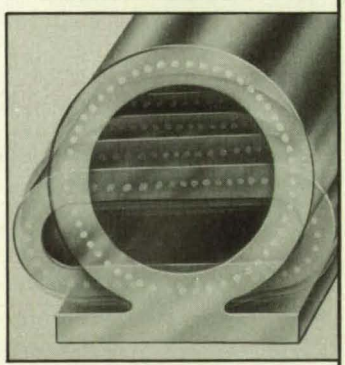
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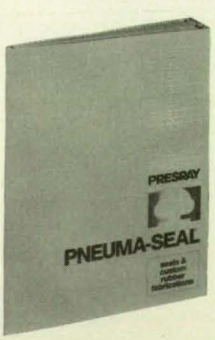
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Enzymatic Catalytic Beds for Oxidation of Alcohols

Treatment of wastewater is enhanced.

Marshall Space Flight Center, Alabama

Modules containing beds of enzymatic material that catalyze the oxidation of primary alcohols and some other organic compounds are being developed for use in the wastewater-treatment systems of future spacecraft. These modules are designed to be placed downstream of multifiltration modules, which contain filters and sorbent beds that remove most of the nonalcoholic contaminants but fail to remove significant amounts of low-molecular-weight, polar, nonionic compounds like alcohols. The catalytic modules might also be used on Earth to oxidize primary alcohols and other compounds in wastewater streams and industrial process streams.

The enzymatic catalytic material in the main beds of the modules is an immobilized alcohol oxidase, which is prepared by binding the enzyme to a derivatized supporting material. Under the influence of the catalyst, alcohols react with oxygen dissolved in the water, forming aldehydes and hydrogen peroxide. Under the influence of supported platinum and platinum/ruthenium catalysts, the aldehydes are oxidized further, yielding organic acids, which are then removed by ion exchange. This latter feature is an advantage in that organic acids are more efficiently removable by ion-exchange media and much less toxic than aldehydes are.

The hydrogen peroxide produced in the enzyme-catalyzed reaction would inhibit that reaction if allowed to remain in the catalytic bed. Therefore, the bed includes

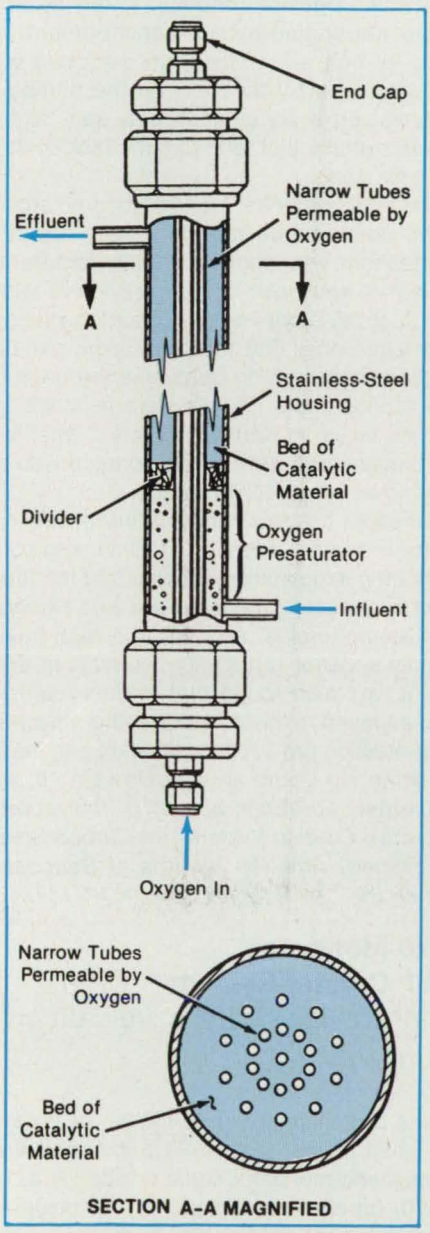
transition metals (e.g., platinum and copper) codeposited with the alcohol oxidase. These metals catalyze the decomposition of the H_2O_2 in situ, thereby increasing the operational life of the bed from what would otherwise be hours, to months.

The dissolved oxygen needed for the catalytic reaction is supplied via an oxygen saturator, which includes a bundle of narrow tubes made of a membrane material that is permeable by oxygen. The water flows through the spaces between the tubes, and oxygen supplied to the insides of the tubes passes through the membranes and dissolves in the water. This device provides an excellent distribution of dissolved oxygen, without the bubbles that would be generated by direct injection of oxygen gas into the water. Bubbles must be avoided: they can be trapped in the bed, where they can cause undesired channeling or obstruction of flow.

The figure shows an integrated reactor module that incorporates both an oxygen saturator and an immobilized alcohol-oxidizing catalyst. This reactor oxidizes contaminants at higher concentrations than does a reactor that operates at the same pressure but without a built-in oxygen saturator, because in this reactor there is a favorable shift in chemical equilibrium when oxygen is replenished via the membranes as it is consumed in the reaction.

This work was done by Clifford D. Jolly and Leonard J. Schussel of Umpqua Research Co. for **Marshall Space Flight Center.** *For further information, Circle 41 on the TSP Request Card.*

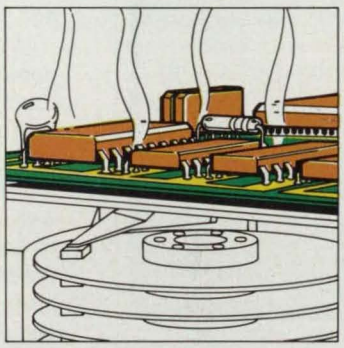
Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 20]. Refer to MFS-26192.



This **Integrated Reactor Module** contains both an alcohol-oxidizing catalytic bed and an oxygen saturator. It performs better than does a catalytic bed placed downstream of a separate oxygen-saturator module.

PROBLEM?

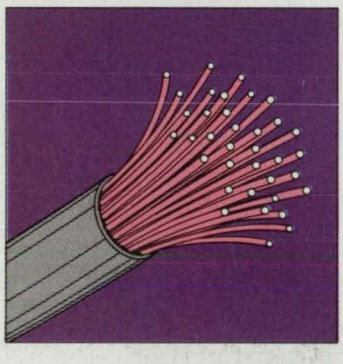
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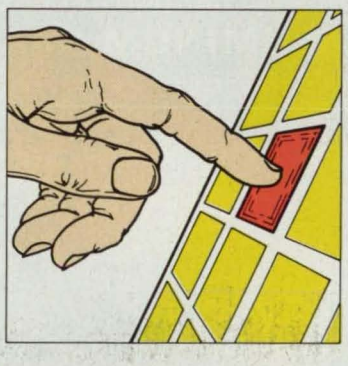
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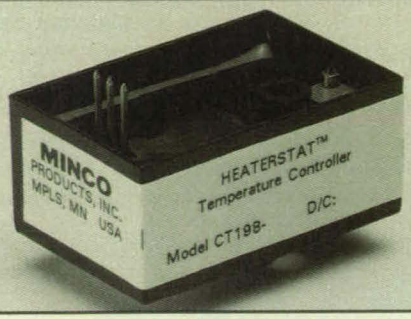
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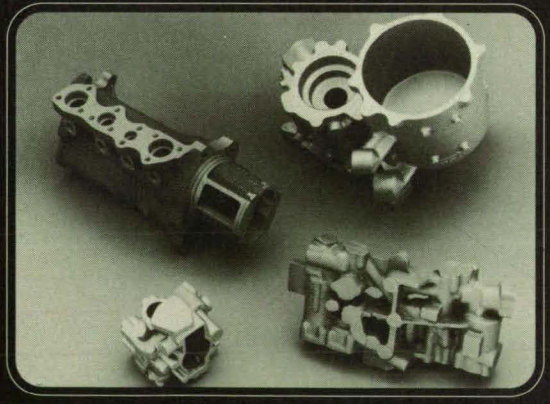
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Books and Reports

These reports, studies, handbooks are available from NASA's as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Protective Coats for Zinc-Rich Primers

In an acidic environment, epoxy/polyurethane topcoats retard corrosion.

A report describes tests of topcoats for inorganic zinc-rich primers on carbon steel. The topcoats are intended to provide additional protection against corrosion in the acidic, salty seacoast-air/rocket-engine-exhaust environment of the Space Shuttle launch site. The tests focused on polyurethane topcoats on epoxy tie coats on the primers. Part of this study involved a comparison between "high-build" coating materials (those that tend to form thick coats) and thin-film coating materials.

Twenty-six thin-film and twenty-six high-build commercial epoxy/polyurethane combination topcoats were tested. Each combination topcoat was applied to manufacturers' carbon steel panels that had been coated previously with the particular manufacturer's commercial zinc-rich primer that is specified for use under that topcoat. Some panels were subjected to laboratory tests to determine the degree of adhesion of the various coats. Panels were exposed to the environment at the beach at Kennedy Space Center for 18 months. Some panels were periodically sprayed with a slurry of alumina particles in hydrochloric acid.

The panels exposed to the environment were subsequently examined for adhesion, retention of gloss, and corrosion. The results of the examination showed that the topcoats were effective in protecting the inorganic zinc primers in acidic corrosive environments, and that the high-build topcoats were slightly superior to thin-film topcoats in this respect. However, it was also found that in those specimens that were not exposed to the acid slurry, the topcoats interfered with the protection provided by zinc-rich primers.

This work was done by Louis G. MacDowell, III, of **Kennedy Space Center.** *To obtain a copy of the report, "Evaluation of Protective Coating Systems for Carbon Steel exposed to SRB Effluent After 18 Months of Seacoast Exposure," circle 1 on the TSP Request Card. KSC-11481*

Shear-Sensitive Monomer/ Polymer Liquid Crystal System

The system may provide quantitative data on flows in wind tunnels.

A report describes a preliminary investigation of a new monomer/polymer liquid crystal system—a thin film of the shear-sensitive cholesteric monomer liquid crystal (TI 511) on a Xydar (STR800) (or equivalent) liquid crystal polymer substrate. Monomer/polymer liquid crystal films applied to surfaces provide quantitative indications of the shear stresses caused by winds blowing along the surfaces. Unlike in the monomer-liquid crystal/metal coating systems used thus far to make flows on the surface of wind-tunnel models visible, the effects of shear stresses are reversible in the new coating system.

Both monomer and polymer cholesteric liquid crystal exhibit selective reflection of light at the wavelength, λ_s, that equals

the average refractive index of the liquid crystal multiplied by the pitch of the helical structure. The pitch of a shear-sensitive cholesteric liquid crystal decreases with shear stress. When the shear stress is increased, the gradual winding of the helix can be observed under white illumination as a dramatic change of the color of reflected light from red to blue.

Because of the high viscosities of liquid crystal polymers, the shear stresses required to modify the helical structures in them are too high at the windspeeds of most interest. Monomer cholesteric liquid crystals have been used to make subsonic and supersonic flows visible. However, they have yielded few reliable quantitative data on the flows because their relatively low viscosities, combined with the poor wettability of the surfaces of conventional models, cause the liquid crystal coats to be thinned and ultimately washed away.

The polymer liquid crystal used in of these experiments can be formed into a plastic that has the strength of steel, the light weight of aluminum, and a melting temperature greater than 350 °C. The liquid crystallinity of the orientations of the polymeric chains is stronger on the surface than in the bulk of the compression-molded samples. These surface orientations were expected and found to induce adequate wettability as well as the formation of a stable Grandjean texture (associated with planar orientation) in the overlying monomeric liquid crystal because of steric interactions between the surface of the polymer and the layer of monomer (which was 20 to 50 μm thick). The contrast of the selectively reflected light was improved by providing a thin black coat at the interface between the monomer and polymer. This black coat was thin enough that steric interactions between the monomer and polymer remained strong enough to maintain the Grandjean texture.

In the experiments, monochromatic light was shone on the liquid crystal coat at an angle of incidence of about 15°, and the intensity of light reflected perpendicularly to the surface was measured as a function of wavelength to determine λ_s. These measurements were performed while air was blown along the surface, driven by a differential pressure Δp. (It was shown by a simple mathematical model of viscous flow that the shear stress caused by the flow is proportional to Δp.) The measurements showed that over the range of pressures from 0 to 100 mm Hg (0 to 13.3 kPa), λ_s decreases approximately linearly with Δp. Furthermore, the effects of shear stress are reversible. Thus, this system may be suitable for measurement of shear stresses caused by flows.

This work was done by Jag J. Singh, Abe Eftekhari, and D. S. Parmar of **Langley Research Center**. *To obtain a copy of the report, "A Shear Sensitive Monomer-Polymer Liquid Crystal System," Circle 21 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 20]. Refer to LAR-14654.

More Cyclic-Oxidation Data for Turbine Alloys

Weight-change and x-ray diffraction data complete a presentation begun in an earlier report.

A document presents data on cyclic oxidation of high-temperature, high-strength, nickel-base and cobalt-base alloys for turbines. The document completes the presentation of data begun in NASA Technical Memorandum 83665 (Revised 1989), "High-Temperature Cyclic Oxidation Data, Turbine Alloys, Part 1."

The data consist of plots and tabulations of changes in specific weight as a function of time, and lists of surface and spalled material phases identified by x-ray diffraction measurements. The data cover 36 alloys: 33 nickel-based and 3 cobalt-based. Most are cast alloys, although a few, such as Waspaloy, René 41, and U-520, are hot-worked wrought alloys.

For each alloy, the data are listed in sequence from higher to lower temperature and from long to short cycle times. Most oxidation tests were conducted at 1,150 °C for 100 hours or at 1,100 °C for 200 hours. Most test cycles were 1 hour long with at least 20 minutes at ambient temperature between cycles. Specimens were removed and weighed at a standard series of times sufficient to generate specific-weight-change/time changes.

In general, the oxidation data follow a paralinear curve: the specific weights increase with time more or less parabolically, then fall linearly. Where the data on specimens of a given alloy differ significantly, there is a corresponding variation in oxide(s) detected by x-ray diffraction.

This work was done by Charles A. Barrett and Ralph G. Garlick of **Lewis Research Center**. *Further information may be found in NASA TM-101468 [N91-10150], "High-Temperature Cyclic Oxidation Data — Turbine Alloys, Part 2."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
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Computer Programs

These programs may be obtained at a very reasonable cost from COSMIC, a facility sponsored by NASA to make computer programs available to the public. For information on program price, size, and availability, circle the reference number on the TSP and COSMIC Request Card in this issue.

Physical Sciences

Global Reference Atmospheric Model — 1990

A coordinated collection of mathematical models of the atmosphere has been updated.

The Global Reference Atmospheric Model was created to satisfy a need for engineering-reference mathematical models of the atmosphere that have wide scope and are widely applicable. GRAM-90, an improvement on the original model, provides values of atmospheric parameters, either automatically at positions along a linear path or along any set of connected positions specified by the user. The parameters produced include monthly total and mean values of pressure, density, temperature, and wind, as well as perturbation values and magnitudes.

GRAM-90 incorporates two older empirical mathematical models of the low and high regions of the atmosphere, plus a mathematical model of the middle region that includes dependences on latitude and longitude. The highest region (altitudes above 120 km) is simulated by an updated version of the Jacchia model, called the Marshall Engineering Thermosphere. The latitude-and-longitude-dependent model applies at altitudes from 30 to 90 km. A mathematical model for the region of transition (altitudes of 90 to 120 km) between the foregoing high regions is synthesized smoothly by use of fairing techniques. The lowest region of the atmosphere (altitudes below 25 km) is simulated by a four-dimensional worldwide mathematical model. An interpolation scheme is used for the region of transition (altitudes of 25 to 30 km) between the middle and low regions.

GRAM-90 also provides the thermal wind shear for the monthly mean winds, the percent deviation from the standard atmosphere, the mean vertical wind, and the perturbation data for each position. Perturbation data consist of values of quasi-biennial and random perturbations.

Improvements of GRAM-90 over GRAM 88 have been made in the four-dimensional and the middle-atmosphere sections. A routine that reads the four-dimensional data by random access from disk files was incorporated, providing for substantial increases in the speeds of execution of some simulations. For the first time, data for the middle atmosphere include explicit Southern-Hemisphere data (as opposed to reflected Northern-Hemisphere data used previously) and zonal mean and latitude–longitude cross-section data for zonal and meridional wind components, replacing the spherical-harmonic mathematical model of wind. Also, the new version contains more-realistic values of temperature extrapolations for the polar areas.

GRAM-90 is written in FORTRAN 77 for batch execution on the IBM 3090 computer. The standard distribution medium for GRAM-90 is a set of two unlabeled, 9-track, 1,600-bit/in. (630-bit/cm) magnetic tapes written in ASCII format with fixed blocks, using a block size of 8,000 and a logical record length of 80. The logical record length of 80 was chosen to enable the tapes to be readable on non-IBM computers. However, before the program can be used successfully on other computers, some of the provided IBM job-control language will have to be translated into code suitable for those computers. The original GRAM code was developed in 1976, and GRAM-90 was released in 1991.

IBM is a registered trademark of International Business Machines Corp.

This program was written by C. G. Justus, F. N. Alyea, D. M. Cunnold, Dale L. Johnson, and William R. Jeffries III of the Georgia Institute of Technology for **Marshall Space Flight Center**. *For further information, Circle 71 on the TSP Request Card.*
MFS-28577

Materials

Predicting Formation of σ Phase in Alloys

SUPER PHACOMP also computes other properties of alloys.

An iron-, nickel-, or cobalt-based alloy composition can cause the alloy to form σ phase when treated at high temperature. Any formation of σ phase is undesirable because it weakens the alloy. The PHACOMP algorithm was developed because of the need to screen any hypothetical or developmental alloy for either the formation or the propensity for formation of the σ phase. On the basis of the alloy composition only, the algorithm can predict the formation of the σ phase.

SUPER PHACOMP was developed after research into the many versions of the PHACOMP algorithm. The resulting program implements three of these versions, enabling comparison of results to give greater reliability to the predictions. Inasmuch as certain calculations are common to each, the three versions were woven together for efficiency. While the prediction of formation of the σ phase is its primary function, SUPER PHACOMP also performs other calculations of the properties of alloys. This program could benefit anyone working in the design of alloys.

The prediction of formation of the σ phase is based upon the energy densities of the alloy elements. A PHACOMP number based on Pauling's density-of-states predictions has been assigned to each of the transition elements. SUPER PHACOMP first reduces the alloy to the γ phase and then calculates a weighted sum of the PHACOMP numbers assigned to the corresponding elements of the alloy. Accompanying each of these values is the prediction of formation of the σ phase for each of the three weighting methods used.

SUPER PHACOMP provides additional calculations of the stacking-fault energy of the austenitic phase and of the weight

of the γ' phase. Also, it identifies the alloy as being nickel-, cobalt-, or iron-based and calculates the carbide content.

SUPER PHACOMP is written in BASIC for IBM PC-series or compatible computers running MS-DOS v3.30 or later. No executable codes are included with the distribution. The source code should be compatible with any DOS-based BASIC language interpreter. SUPER PHACOMP requires 640K of random-access memory for execution. This package of software is available on a 5.25-in. (13.34-cm), 360K, MS-DOS-format diskette. SUPER PHACOMP was developed in 1991.

IBM PC is a trademark of International Business Machines Corp. MS-DOS is a registered trademark of Microsoft Corp.

This program was written by William F. Kaukler and Gary L. Workman of the University of Alabama in Huntsville for **Marshall Space Flight Center**. *For further information, Circle 70 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 20]. Refer to MFS-26164.

Computing Reliabilities of Ceramic Components

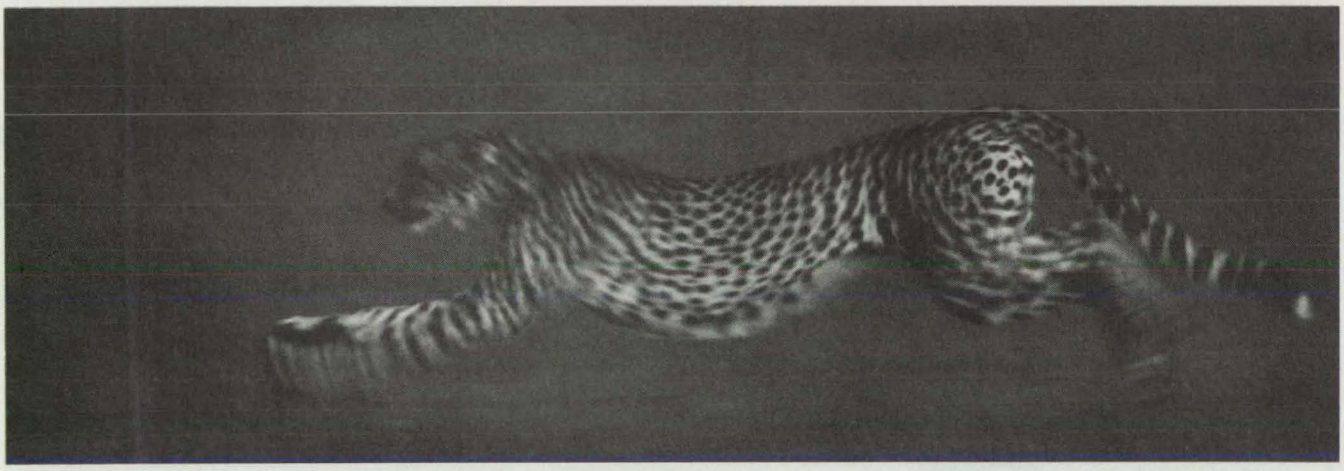
CARES/PC analyzes data from fractured specimens.

The beneficial properties of structural ceramics include high-temperature strength, light weight, hardness, and resistance to corrosion and oxidation. The ability of ceramics to function in advanced heat engines at temperatures well beyond the operational limits of metals has been demonstrated. This is offset by the fact that ceramic materials tend to be brittle. When a load is applied, the lack of significant plastic deformation causes the material to crack at microscopic flaws, destroying a component made of such a material.

The CARES/PC computer program performs statistical analysis of data obtained from the fracture of simple, uniaxial tensile or flexural specimens of ceramics and estimates the Weibull and Batdorf material parameters from these data. CARES/PC is a subset of the Ceramics Analysis and Reliability Evaluation of Structures (CARES) program (COSMIC program number LEW-15168), which calculates the fast-fracture reliabilities or failure probabilities of ceramic components by use of the Batdorf and Weibull models to describe the effects of multiaxial stress states on the strengths of materials. The use of CARES requires the mathematical modeling of the ceramic components by a finite-element program like MSC/NASTRAN or ANSYS. The more-limited CARES/PC does not calculate the fast-fracture reliabilities of components.

CARES/PC estimates selected properties of ceramic materials from data taken in uniaxial tensile tests or three- and four-point-bend-bar tests. In general, the parameters used in CARES/PC are obtained from the fracture stresses of many specimens (30 or more are recommended), the shapes, sizes, and loading configurations of which are held constant. Weibull parameters of single- or multiple-failure modes can be estimated by using the least-squares analysis or the maximum-likelihood method. Kolmogorov–Smirnov and Anderson–Darling goodness-of-fit tests measure the accuracy of the hypothesis that a given set of fracture data come from a population, the distribution of which is specified by the estimated Weibull parameters. Ninety-percent confidence intervals on the Weibull parameters and the unbiased values of the shape parameters for complete samples are provided when the maximum-likelihood technique is used.

CARES/PC is written and compiled with the Microsoft FORTRAN v5.0 compiler, using the VAX FORTRAN extensions and



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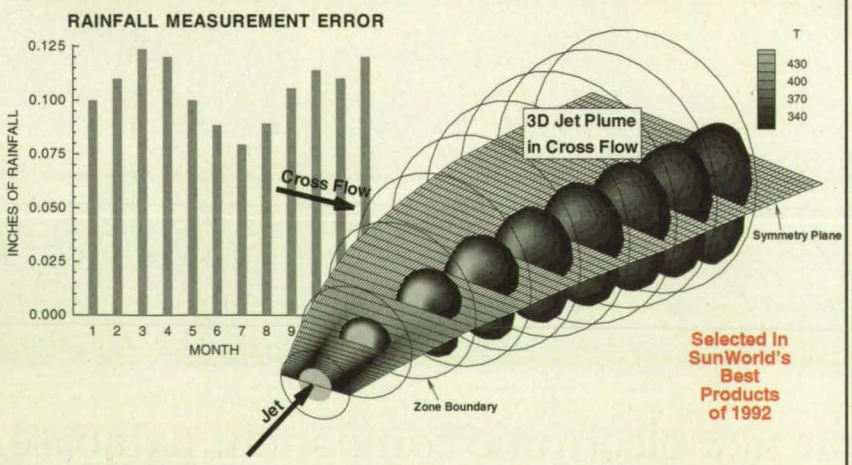
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dynamic array allocation supported by this compiler for the IBM/MS-DOS or OS/2 operating systems. The dynamic array allocation routines enable the user to match the number of fracture sets and test specimens to the memory available. The required equipment includes an IBM PC-compatible computer with optional math coprocessor. The output of the program is designed to fit 80-column-format printers. Executable codes for both DOS and OS/2 are provided. CARES/PC is distributed on one 5.25-in. (13.34-cm) 360K MS-DOS-format diskette in compressed format. The expansion tool PKUNZIP.EXE is supplied on the diskette. CARES/PC was developed in 1990.

IBM PC and OS/2 are trademarks of International Business Machines Corp. MS-DOS and MS OS/2 are trademarks of Microsoft Corporation. VAX is a trademark of Digital Equipment Corp.

This program was written by S. A. Szatmary, J. P. Gyekenyesi, and N. N. Nemeth of Aerospace Design and Fabrication, Inc., for **Lewis Research Center**. *For further information, Circle 99 on the TSP Request Card. LEW-15248*

Mechanics

Analyzing Impacts of Meteoroids and Debris on Spacecraft

Designs can be analyzed and optimized to minimize numbers of penetrations.

BUMPERII is a modular computer program that implements a numerical solution technique to calculate the probability of no penetration (PNP) of a spacecraft by orbiting artificial debris or impacts of meteoroids. The equation used to calculate the PNP is based on a Poisson-distribution model applicable to similar analysis of smaller craft, but reflects the more rigorous mathematical modeling of the size, shape, orientation, and other characteristics of a spacecraft that affect impacts and that are necessary for PNP analyses of such larger structures as components of a space station. The technique involves the consideration of the surface of the spacecraft in terms of a series of flat plate elements. The program divides the threat environment into a number of finite cases, then evaluates each element of each threat. The code allows for impact shielding (shadowing) of one element by another in various configurations over the outside of the spacecraft, and for the effects of changing orientation of the spacecraft.

BUMPERII comprises three main mod-

ules: GEOMETRY, RESPONSE, and SHIELD. The GEOMETRY module accepts finite-element-model representations of the size and shape of the spacecraft as specified by the user and creates geometry data bases for analysis with respect to meteoroids and analysis with respect to debris. Input to the GEOMETRY module is required to be in the SUPERTAB Universal File Format because the developers of the original BUMPER code used the finite-element-model program SUPERTAB to build their mathematical models.

The RESPONSE module creates wall-penetration-response data bases — one for analysis with respect to meteoroids and one for analysis with respect to debris — for as many as 100 unique wall configurations. This module also creates a file that contains critical diameter as a function of impact velocity and impact angle for each wall configuration.

The SHIELD module calculates the PNP for the modeled structure, given exposure time, operating altitude, ranges of inside diameters of elements, and the data from the RESPONSE and GEOMETRY data bases. The results appear in a summary file. SHIELD also determines the effective areas of the components and the overall model, and it can produce a data file that contains the probability of penetration per surface area for each element in the model. The SHIELD module writes this data file in SUPERTAB Universal File Format so that threat-contour plots can be generated by use of a postprocessing feature of the finite-element-model program SUPERTAB.

Users can perform sensitivity studies of two kinds. The effects of simple variations in orbital time, surface area, and flux can be analyzed by making changes in the terms that represent the average number of penetrating particles per unit time in the PNP equation. The program analyzes other changes, including model environment, surface area, and configuration, by rerunning the solution sequence with new GEOMETRY and RESPONSE data.

BUMPERII is written in FORTRAN 77 for DEC VAX-series computers under VMS, and was written for use with the finite-element-model code SUPERTAB as both a preprocessor and a postprocessor. The use of an alternate finite-element model necessitates either the development of a translator to change the data format or modification of the GEOMETRY subroutine in BUMPERII. This program is available in DEC VAX BACKUP format on 9-track, 1,600-bit/in. (630-bit/cm) magnetic tape (standard distribution medium) or on TK50 tape cartridge. The original BUMPER code was developed in 1988; the BUMPERII revision followed in 1991.

SUPERTAB is a former name for I-DEAS. I-DEAS Finite Element Modeling is a trademark of Structural Dynamics Research Corp. DEC VAX is a trademark of Digital Equipment Corp.

This program was written by Mike Bjorkman of The Boeing Co. for **Marshall Space Flight Center**. *For further information, Circle 65 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 20]. Refer to MFS-28565.

Mathematics and Information Sciences

Risk-Assessment Computer Program

RISK D/C allows for the subjectivity of risk assessment in early phases of planning.

RISK D/C is a prototype computer program that assists in attempts to do program risk modeling for the Space Exploration Initiative (SEI) architectures proposed in the Synthesis Group Report. Risk assess-



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ment is performed with respect to risk events, their probabilities, and the severities of potential results. RISK D/C enables the ranking, with respect to their effectiveness, of risk-mitigation strategies to be proposed for an exploration program architecture.

RISK D/C allows for the fact that risk assessment in early phases of planning is subjective. Although specific to the SEI in its present form, RISK D/C can be used as a software framework for the development of risk-assessment programs for other specific uses.

RISK D/C is organized into files, or "stacks," of information, including the architecture, the hazard, and the risk-event stacks. Although predefined, all stacks can be upgraded by a user. The architecture stack contains information concerning the general program alternatives, which are subsequently broken down into waypoints, missions, and mission phases. The hazard stack includes any background condition that could result in a risk event. A risk event is anything unfavorable that could happen during the course of a specific point within an architecture, and the risk-event stack indicates the probabilities, consequences, severities, any mitigation strategies that could be used to reduce the risk of the event, and how much the risk is reduced.

RISK D/C was developed for Macintosh-series computers. It requires HyperCard 2.0 or later, as well as 2 Mb of random-access memory and System 6.0.8 or later. A Macintosh II-series computer is recommended because of concerns of speed. The standard distribution medium for this package is one 3.5-in. (8.89-cm), 800K Macintosh-format diskette. RISK D/C was developed in 1991 and is a copyrighted work with all copyright vested in NASA.

Macintosh and HyperCard are trademarks of Apple Computer, Inc.

This program was written by William C. Dias and David S. Mittman of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 60 on the TSP Request Card.* *NPO-18740*

Image-Enhancement Program

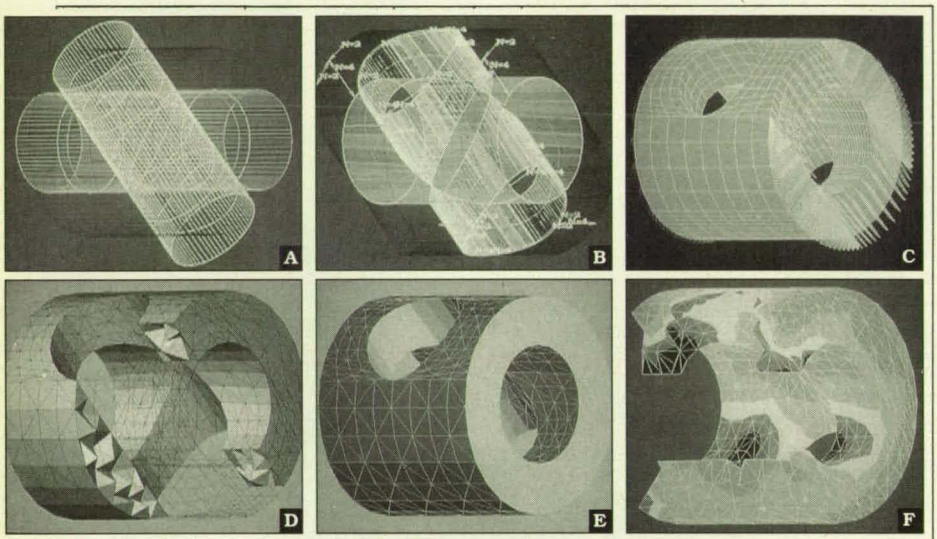
ENHANCETOOL contains a unique, useful combination of algorithms.

The ENHANCETOOL computer program has the capabilities for interactive enhancement of digital images. While such capability is not unique, ENHANCETOOL includes a particularly useful combination of algorithms that do not exist elsewhere in a single interactive program. This software package also provides a means through which additional image-enhancement algorithms can easily be integrated and made available to the user.

ENHANCETOOL enables the researcher to perform a variety of enhancements on digital images. It can handle local and global contrast enhancements, histogram modifications, and lookup-table transformations of an image. The user can modify the image in the following ways: long-range modification, automatic linear contrast stretch, logarithmic transformation, square-root transformation, digital negative, intensity-level slicing, histogram equalization, histogram specification, and application of specific color lookup tables. As these modifications are applied, both the original image and the modified image are displayed, enabling simple comparison. When needed, the enhancement parameters are specified by the user. Otherwise, the enhancement is done immediately following selection.

ENHANCETOOL is written in C Language for Sun-series computers that have color or gray-scale-display capabilities and that run Sunview or OpenWindows under SunOS. No binaries are included with this distribution. ENHANCETOOL requires 200K of random-access memory for execution. The standard distribution medium is a 0.25-in. (6.35-mm) streaming-magnetic-tape cartridge in UNIX tar format. ENHANCETOOL was developed in 1991.

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This program was written by Christine G. Matthews of Computer Sciences Corp. and Kathryn Stacy of **Langley Research Center**. *For further information, Circle 94 on the TSP Request Card.*
LAR-14748

Program for Workload and Performance Experiments

MAT provides benchmark tasks analogous to those of aircraft crewmembers.

The Multi-Attribute Task (MAT) battery of computer programs gives the researcher the capability of performing experiments in multitask workloads and performances. The battery provides a benchmark set of tasks for use in a wide range of laboratory studies of operator performance and workload. MAT incorporates tasks analogous to activities that aircraft crewmembers perform in flight, while providing a high degree of experiment control, performance data on each subtask, and freedom to use nonpilot test subjects.

The primary display of the MAT battery is composed of four separate task windows as follows: a monitoring task window, which includes gauges and warning lights; a tracking task window for the demands of manual control; a communication task window to simulate air-traffic-control communications; and a resource-management task window, which enables the maintenance of target levels on a fuel-management task. In addition, a scheduling task window gives the subject information about future task demands. The battery also provides the option of manual or automated control of tasks. Each task generates performance data for each subtask. A battery of tasks can be made to pause, and during the pause, workload-rating scales can be presented to the subject on the display unit.

The MAT battery was designed to use a serially linked second computer to generate the voice messages for the communication task. The MATREMX program and support files, which are included in the MAT package, were designed to work with the Heath Voice Card (Model HV-2000, available through the Heath Co., Benton Harbor, Michigan 49022); however, the MATREMX program and support files can be modified easily to work with other voice-synthesizer or digitizer cards. The MAT-battery-task computer can also be used independently of the voice computer if no computer-synthesized voice messages are desired or if some other method of presenting auditory messages is devised.

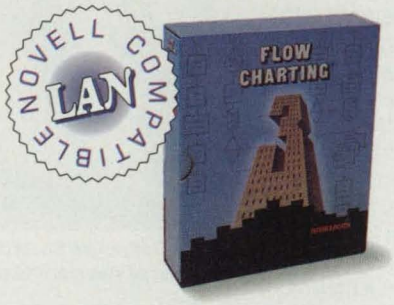
MAT is written in QuickBasic and Assembly language for IBM PC series and compatible computers running MS-DOS. The code in MAT is written for Microsoft QuickBasic 4.5 and Microsoft Macro Assembler 5.1. This package requires a joystick and EGA or VGA color graphics. An 80286-, 386-, or 486-processor computer is highly recommended. The standard distribution medium for MAT is a 5.25-in. (13.34-cm), 360K diskette in MS-DOS format. The files are compressed by use of the PKZIP file-compression utility program. PKUNZIP is included on the distribution diskette. MAT was developed in 1992.

IBM PC is a registered trademark of International Business Machines Corp. MS-DOS, Microsoft QuickBasic, and Microsoft Macro Assembler are registered trademarks of Microsoft Corp. PKZIP and PKUNZIP are registered trademarks of PKWare, Inc.

This program was written by J. Raymond Comstock, Jr., of **Langley Research Center** *and Ruth J. Arnegard of Old Dominion University. For further information, Circle 34 on the TSP Request Card.*
LAR-14904

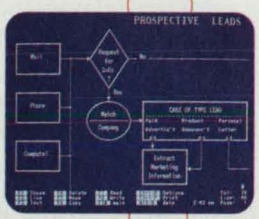
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Optical Shaft-Angle Encoder for Helicopter Rotor

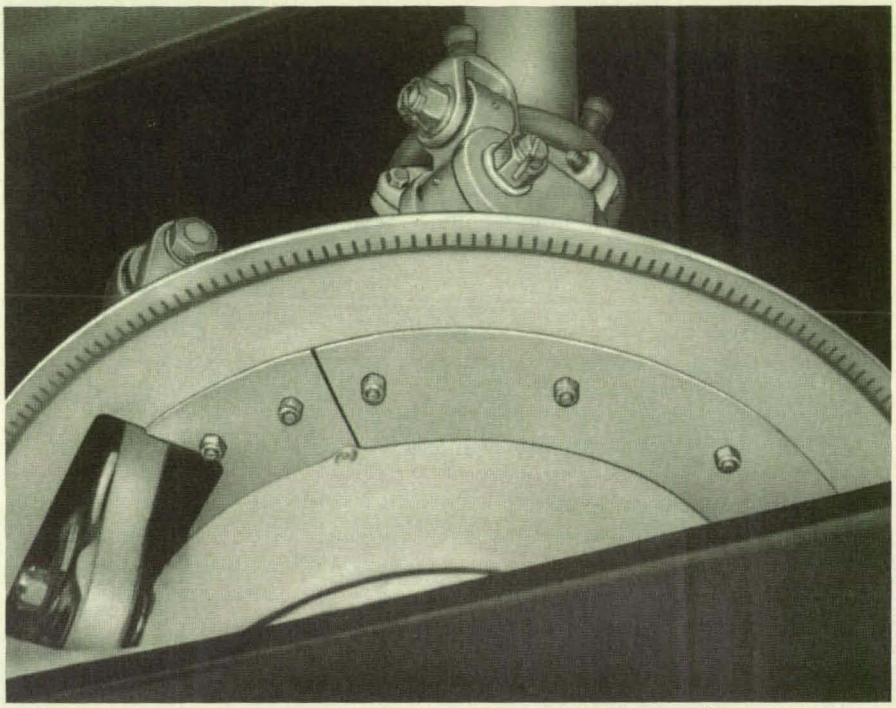
The angular position of a helicopter rotor blade is determined precisely.

Langley Research Center, Hampton, Virginia

In noise-analysis research regarding the rotation of the main rotor blade of a helicopter, it became necessary to correlate noise with the exact position of the blade. In order to do this, a method was devised to determine the position of the blade at any time precisely. This was accomplished by the use of an optical shaft-angle encoder called the "256 Ring" on the rotor swashplate.

Each 360° rotation of the helicopter main rotor was broken down into 256 reflective segments, 1.40625° each, by fabricating a ring of fiberglass printed-circuit material with 256 segments etched and nickel-plated on one surface (see figure). The ring was mounted on the rotor swashplate. As the rotor rotates, a beam of light is reflected in turn from each segment into an optoelectronic system. One of the 256 segments reflects a larger pulse than the others do. The position of the rotor can thus be determined by counting the number of pulses after this reference pulse.

Two rings of different size, for different helicopters, have been flown for over 100 hours. The flight tests were highly successful. One ring was flown at a maximum speed of 500 rpm with a maximum rotational-position error of ± 0.075°. The other was flown at a maximum of 350 rpm, with a maximum rotational-position error of ± 0.014°. While swashplate mounting requirements may be unique to each type of helicopter, this concept is applicable to all types of rotorcraft.



The **Reflective Surfaces of 256 Segments** enable precise determination of the rotational position of the rotor blades.

This work was done by Robert A. Golub and Fred Fitzpatrick of **Langley Research Center** *and Dale V. Dennis and Bryant D. Taylor of Planning Research Corp. No further documentation is available.*
LAR-14123

Compliant Gearing for Redundant Torque Drive

Elastomeric bearings make torque loads more nearly equal.

Lewis Research Center, Cleveland, Ohio

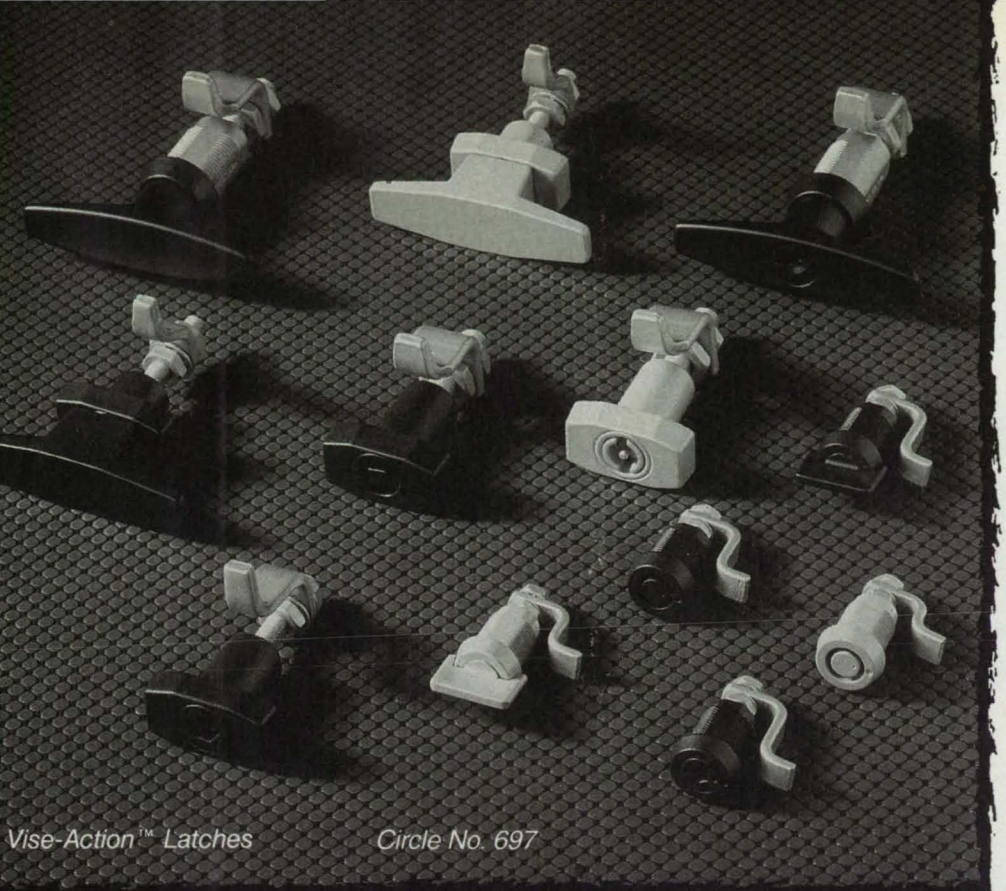
A set of elastomeric bearings constitutes a springy coupling between a spur gear and a drive shaft. The gear, bearings, and shaft are parts of a split-drive (redundant) mechanical transmission, and the compliance of the coupling helps to distribute torque nearly equally along the load paths of the split drive. Compliance is necessary because without it, even slight deviations in the dimensions of the redundant gears can cause grossly unequal sharing of loads. Indeed, in the absence of compliant coupling, the gears along one load path can assume the entire load while those along another load path can freewheel. Thus, the advantage of reduced loads on gear teeth is lost.

The figure illustrates one version of the shaft/bearing/gear assembly. An inner, concentric elastomeric bearing lies between a central drive shaft and an extension of a ring spur gear. A set of padlike outer elastomeric bearings joins outward protrusions on an extension of the drive shaft with facing inward protrusions on the ring spur gear.

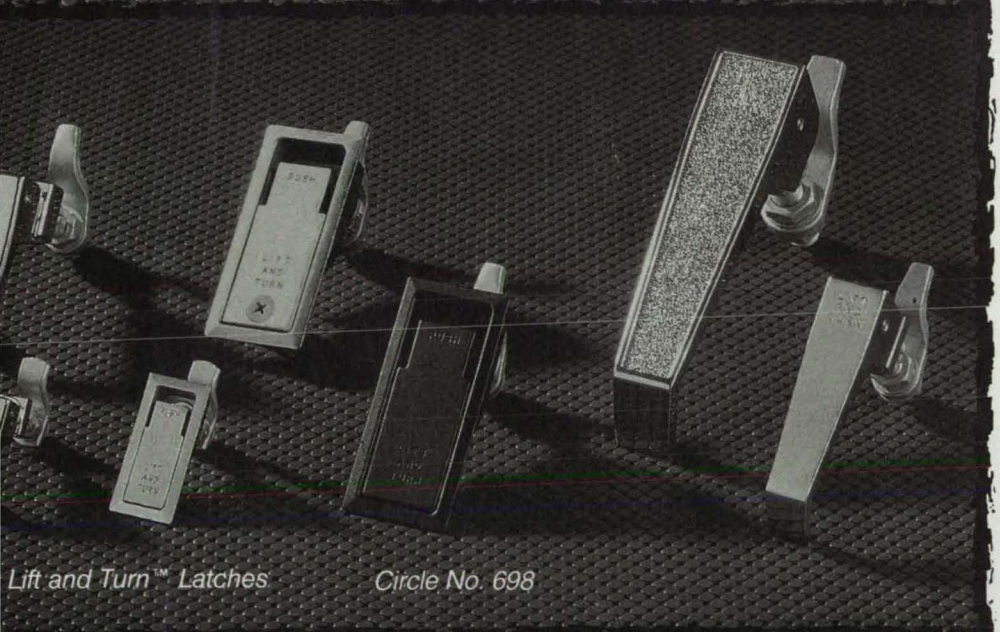
The inner elastomeric bearing has high radial stiffness and low circumferential stiffness. This bearing centers the ring spur gear on the axis of the drive shaft and provides compliance in a circumferential direction. In a representative design of a redundant helicopter transmission, it should be at least 0.5 in. (1.27 cm) thick so that it transmits little torque.

The outer elastomeric bearings, in contrast, have low radial stiffness and high circumferential stiffness. They thus transmit torque effectively between facing protrusions. Nevertheless, they are sufficiently compliant circumferentially to accommodate the desired amount of circumferential displacement [up to $1/16$ in. (1.6 mm) in the helicopter application].

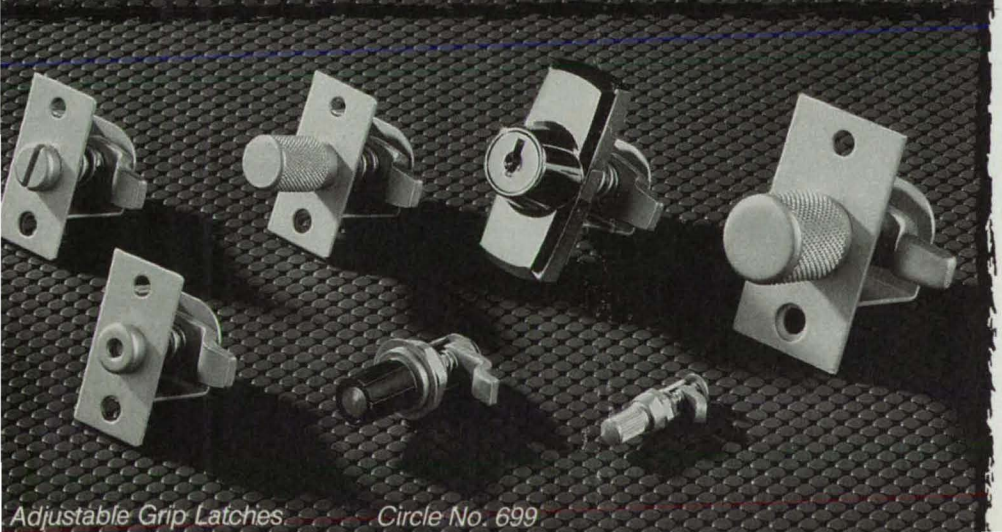
The process of assembling the compliant gearing begins with the pressing of the inner elastomeric bearing onto the drive shaft. Then, with the help of an alignment tool, the ring spur gear is pressed onto the inner elastomeric bearing. The outer elastomeric bearings are ground to fit the spaces between the protrusions and bonded in place on the protrusions. As an alternative to bonding, the entire assembly



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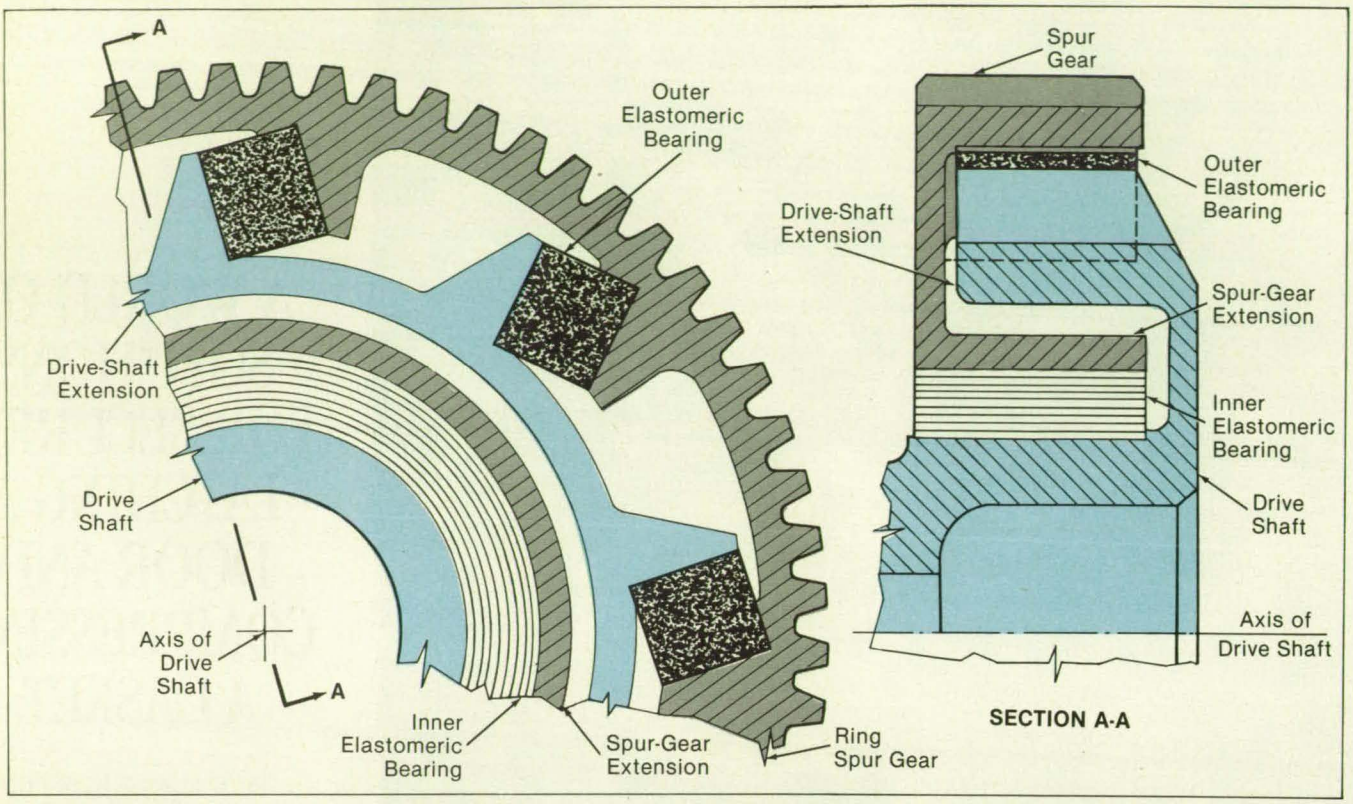
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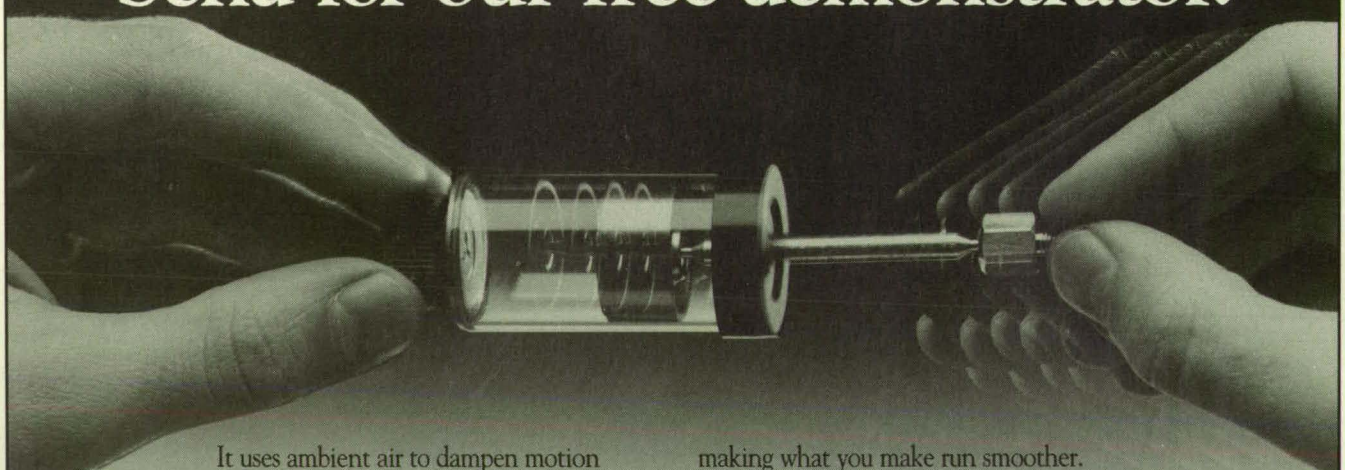
can be potted in a soft matrix that holds the outer bearings in place but allows rotation with little restraint.

This work was done by C. Isabelle and J. Kish of United Technologies Corp. for **Lewis Research Center**. *For further information, Circle 22 on the TSP Request Card.*
LEW-15035



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Open-Mode Delamination in Horseshoelike Specimens

The open-mode-delamination stresses are concentrated in the bends.

Ames Research Center, Moffett Field, California

Tests to determine the open-mode-delamination stresses of laminated composite materials can be improved by the use of horseshoelike (instead of semicircular) curved bar specimens: this is a conclusion drawn from a recent theoretical analysis of the stresses in such specimens. The delamination stress of a given laminate is the purely tensile stress, perpendicular to the planes of the layers, that suffices to pull its laminae apart. The horseshoelike specimens are needed to overcome the deficiencies of specimens of two older types (see Figure 1): In the case of a flat plate specimen, it is difficult to maintain the required parallelism between the platens that are bonded to the outer laminae, and the bond between the specimen and a platen can be broken before delamination occurs elsewhere. In the case of a semicircular specimen, the shear stresses at the ends can be large enough to cause shear-mode delamination prior to open-mode delamination.

Two horseshoelike specimen shapes

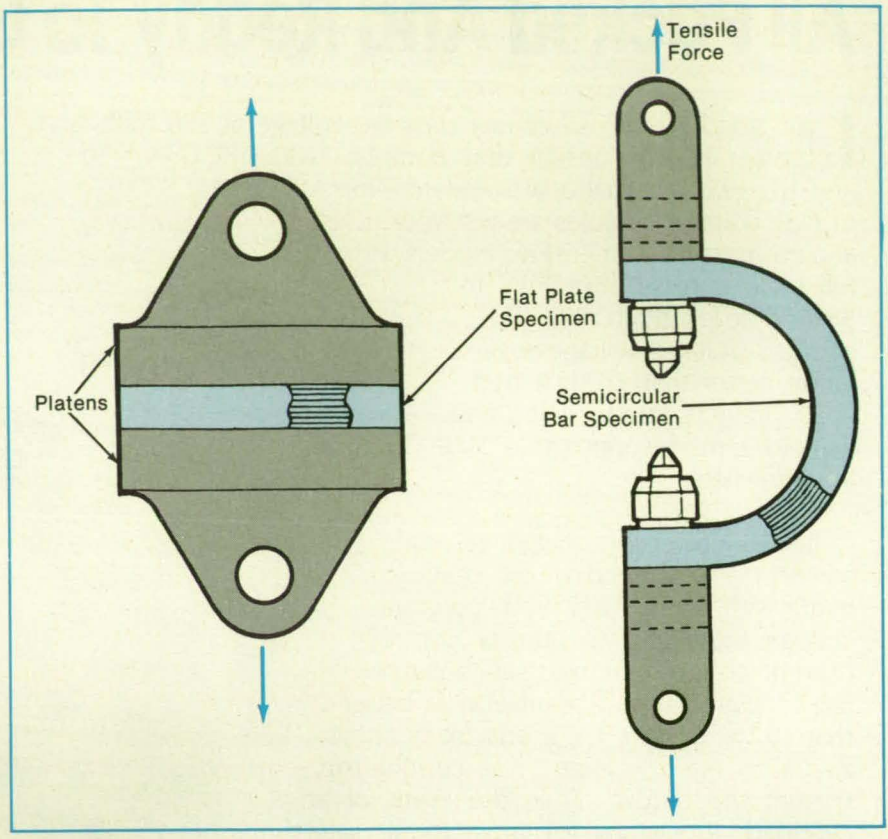


Figure 1. **Flat Plate and Semicircular Bar Specimens** are not well suited for the open-mode delamination tests.

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Letters of nomination must include the organization's name and address, a contact and phone number, and a 150-200 word description of the commercialized product or process, focusing on its importance (such as its economic or social impact) and novelty in the marketplace. The description also should highlight the federal government's role in the technology's development and transfer. Supporting materials may be included with the letter of nomination.

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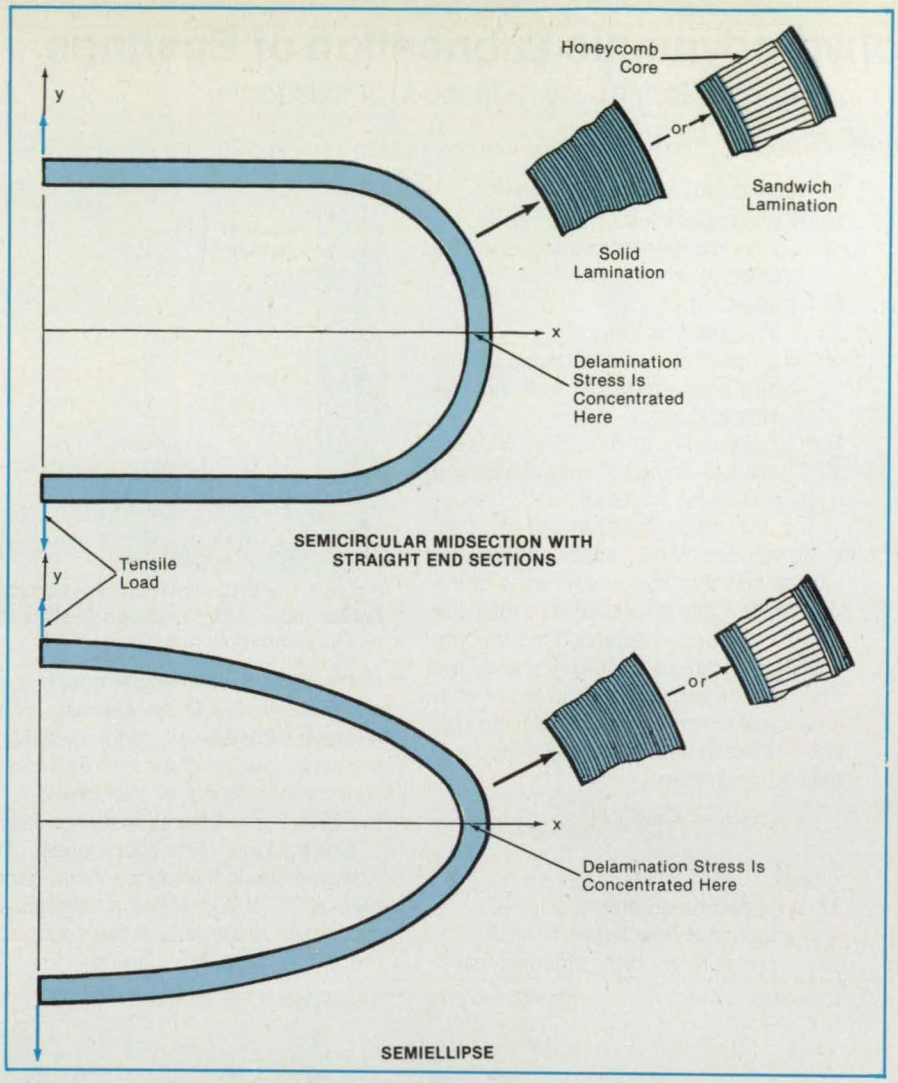


Figure 2. These **Horseshoelike Curved Bar Specimens** have better geometries for the open-mode delamination tests.

have been proposed: one with a semicircular midsection and straight end sections, and one that is essentially half of an ellipse that has been cut along its minor axis (see Figure 2). These shapes are suitable for both solid and sandwich laminates. As in the case of a semicircular bar specimen, the highest open-mode delamination stress occurs at a point within the thickness at the midlength of the specimen (at the middle of the bend).

The depth of the point of maximum delamination stress and the magnitude of this stress depend on the geometry of the specimen and the properties of the material(s). They can be computed analytically by use of a theoretical model of bending of a multilayer semicircular bar (in the case of the semicircular midsection) or by a finite-element structural-analysis computer program (for the elliptical specimen). By suitable choice of the length of the straight sections, which serve as moment arms, one can make the peak delamination stress several times as large as the peak shear stress. A similar effect can be produced in an elliptical specimen by decreasing the ratio between the minor and major axes.

Calculations show that an elliptical horseshoe bar concentrates the delamination stress slightly more than a semicircular/straight bar does. A semicircular/straight bar specimen could be used to determine both the delamination strength of a solid laminate and the debonding strength of a sandwich laminate. An elliptical bar specimen is not suitable for determining the debonding strength of a sandwich laminate.

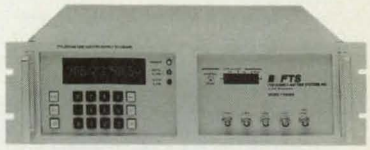
This work was done by W. L. Ko and R. H. Jackson of **Ames Research Center**. *Further information may be found in NASA TM-4164 [N90-16004], "Open-Mode Delamination Stress Concentrations in Horseshoe and Elliptic Composite Curved Bars Subjected to End Forces."*

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For More Information Circle No. 404

Equations for Elastohydrodynamic Lubrication of Bearings

Complicated calculations for rolling-element bearings are reduced to simple terms.

Lewis Research Center, Cleveland, Ohio

The equation for the thickness of an elastohydrodynamic (EHD) lubricant film in a rolling-element bearing has been reduced to a simplified form that involves only the inside and outside diameters of the bearing, the speed of rotation, a parameter related to the type of lubricant, and the viscosity of the lubricant at the temperature of the bearing. In addition, there has now been made available, for the first time, an experimentally derived graph of an EHD-film-thickness-reduction factor as a function of the contact-lubricant-flow number. This reduction factor accounts for lubricant starvation within the Hertzian contact. A graph that relates the ratio of minimum film thickness to the composite roughness of the bearing surfaces and to a lubrication-life correction factor has also been provided. The life-correction factor is used to determine the resultant life of the bearing.

The equation for the theoretical thickness, h_c, of an EHD film is as follows:

$$h_c \approx k_h(\mathrm{OD}-\mathrm{ID})^{0.32}[N(\mathrm{OD}+\mathrm{ID})]^{0.68} Z_0^{0.68} G^{0.49}$$

where

h_c = central or average thickness, of the EHD film, in.

k_h = EHD film factor, in.$^{1.36}$/lb$^{0.68}$

OD = outer diameter, of bearing, in.

ID = inner diameter of bearing (diameter of bore), in.

N = speed, rpm

Z_0 = absolute viscosity, cP

G = a parameter that depends on the lubricant material and on the temperature.

For OD, ID, and h_c in inches, $k_h = 3.8\times 10^{-11}$; for OD and ID in millimeters and h_c in inches, $k_h = 1.49\times 10^{-12}$.

The theoretical thickness of the film, h_c, is reduced by the inability of the lubricant to flow into the contact zone of the bearing at a rate necessary to supply the volume required to establish the theoretical film thickness. Figure 1 shows the EHD-film-thickness-reduction factor as a function of the contact lubricant-flow number. The contact-lubricant-flow number is defined as follows:

$$GU \approx k_G \alpha Z_0 N \left(\frac{\mathrm{OD}+\mathrm{ID}}{\mathrm{OD}-\mathrm{ID}}\right)$$

where:

U = speed parameter

k_G = lubricant flow factor, min/cP

α = pressure-viscosity exponent, psi^{-1}

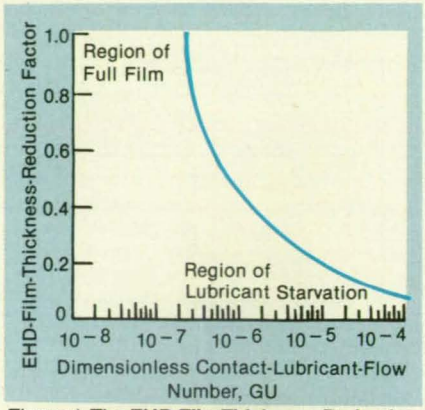


Figure 1. The **EHD-Film-Thickness-Reduction Factor** varies with the dimensionless contact-lubricant-flow number.

For α in square inches per pound, $k_G = 1.52\times 10^{-10}$ min/cP. An estimate of the reduced thickness, h'_c, of the EHD film in the central region of the Hertzian contact zone is then found by multiplying h_c by the EHD-film-thickness-reduction factor.

One measure of the effectiveness of the lubricant film is the lubricant-film parameter, $\Lambda = h'_c/\sigma$, where σ denotes the composite roughness of the surfaces of the rolling elements. Usually,

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$$\sigma = \left(\sigma_1^2 + \sigma_2^2\right)^{1/2}$$

where σ_1 and σ_2 denote the root-mean-square roughnesses (in inches) of the surfaces of two rolling elements in contact with each other. For most commercial off-the-shelf bearings, σ can be taken as 10 μin. (0.25 μm). For most aerospace bearings, σ can be taken as 5 μin. (0.13 μm). For very large industrial bearings, σ can be taken as 25 μin. (0.64 μm).

Figure 2 shows the effect of the thickness of the lubricating film on the life of the bearing. The life-correction factor obtained from this figure can be used to adjust the life of the bearing calculated according to a method promulgated by the innovator in 1986.

This work was done by Erwin V. Zaretsky of **Lewis Research Center**. *Further information may be found in NASA TM-102575 [N90-22041], "Bearing Elastohydrodynamic Lubrication: A Complex Calculation Made Simple."*

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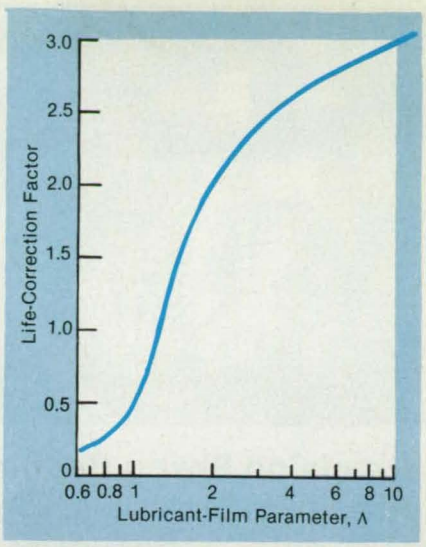


Figure 2. The **Life-Correction Factor** is a function of the lubricant-film parameter, Λ, which is the ratio of the minimum thickness of the EHD film to the composite roughness of the bearing surfaces.

Modified Composite Struts Would Damp Vibrations

The modified struts could be fabricated more easily.

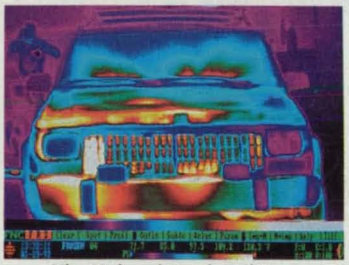
NASA's Jet Propulsion Laboratory, Pasadena, California

Composite-material (fiber/matrix laminate) struts that damp longitudinal vibrations could be fabricated more easily in a proposed new design. The prior design was described in "Composite Struts Would Damp Vibrations" (NPO-17914), *NASA Tech Briefs*, Vol. 15, No. 4 (April, 1991), page 79.

The principle of operation of a vibration-damping composite strut was explained in more detail in the noted prior article. The basic idea is to exploit (1) the anisotropic mechanical properties of two (or more) fiber/matrix layers and (2) the coupling between these layers and an intervening layer or layers of viscoelastic material. In the prior design (see figure), the fibers in the two (or more) fiber/matrix layers would be laid out in opposing chevron patterns. At any given location along the strut, a longitudinal tension or compression load would cause the two (or more) chevron plies to twist in opposite directions about the longitudinal axis, thereby generating

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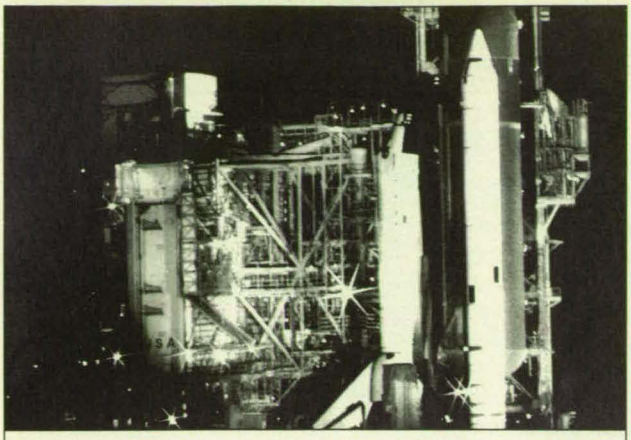
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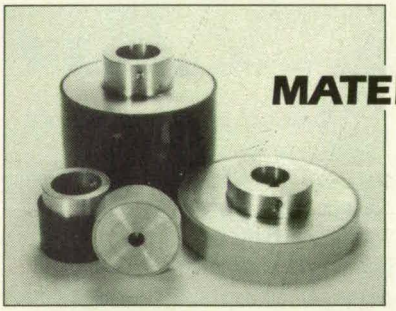
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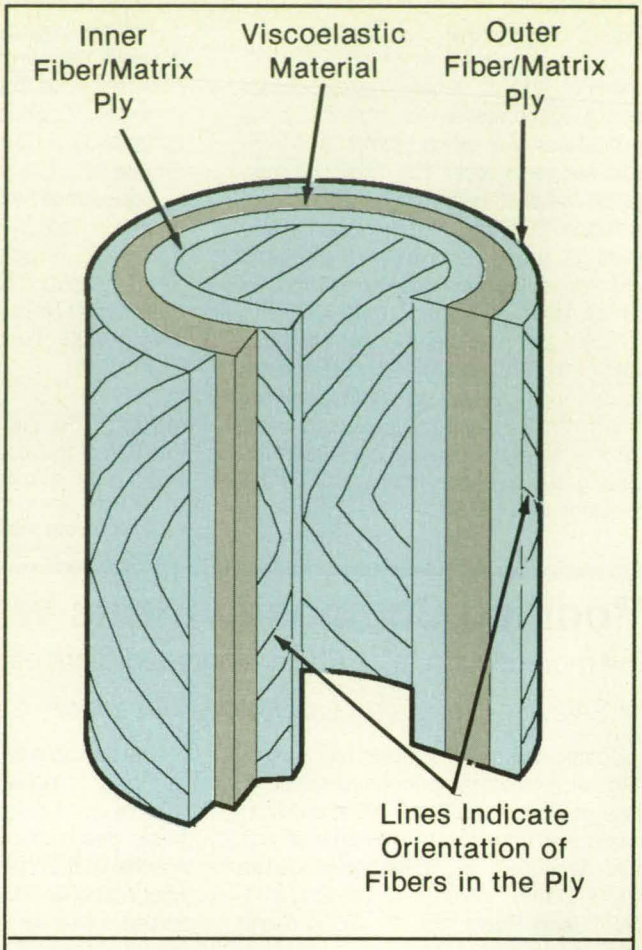
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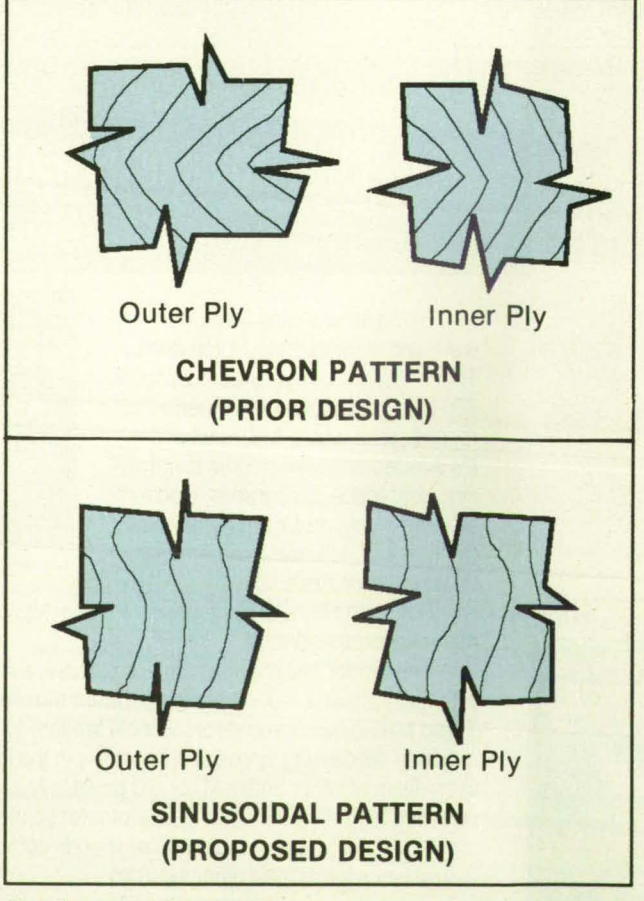
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The Proposed New Design of a damping strut is similar to the prior design, except that the pattern of fibers includes rounded bends (instead of sharp bends) in the fibers. The rounded-bend pattern can be fabricated more easily.

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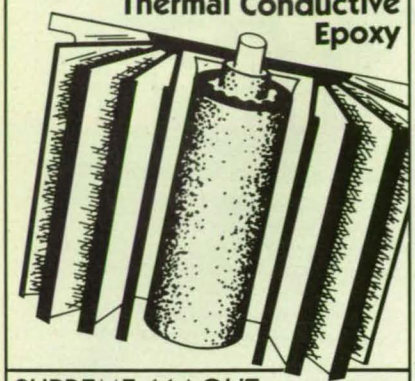
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shear stresses in the viscoelastic layer(s). The stresses and energies of longitudinal vibrations would thus be channeled into the viscoelastic layer(s), where they would be dissipated.

The chevron pattern is useful for theoretical analysis and performance tradeoffs among alternative proposed designs, but is not practical because of its sharp bends in the fibers. In the proposed design, the pattern would be sinusoidal. The sinusoidal pattern can be fabricated more easily. The basic principle of operation is the same as in the case of the chevron pattern, though the details of the local anisotropy and damping response are different.

Theoretical analysis with numerical examples shows that the sinusoidal pattern would produce a little less coupling of deformations into the viscoelastic layer than does a comparable chevron pattern. However, the resulting decrease in damping could be offset by selection of the various geometrical parameters and specifications of materials in the design. A typical optimal combination of parameters should result in a damping factor between 10 and 25 percent — about the same as that of a chevron pattern and of an older damping-member design called "constrained-layer damping treatment," which requires the additional weight of a constraining layer.

This work was done by Gun-Shing Chen and Benjamin P. Dolgin of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 108 on the TSP Request Card.*
NPO-18354

Books and Reports

These reports, studies, handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Repeated Torque Cycles Reduce Bolt Preload

Thread surfaces deteriorate after only a few cycles.

A report describes an experiment to determine the effect of repeated torque cycles upon the preload (tensile force) applied by a bolt tightened to a given torque. The results of the experiment indicate that the preload attainable at a given torque decreases on subsequent cycles.

The experiment was performed on a high-strength, heat-treated, A-286 stainless-steel, $\frac{5}{16}$-in.-24 UNF (approximate metric equivalent 7.94-mm diameter, 1.06-mm pitch; not a standard metric thread) hexagon-head bolt, which had a minimum ultimate tensile strength of 2×10^5 psi (1.4 GPa). A piezoelectric force transducer with a central through hole was stacked between two steel plates with through holes, a hardened steel washer was placed under the bolthead, the bolt thread was sprayed with molybdenum-based lubricant, and the bolt was inserted through the stack. The bolt engaged a steel nut held in the lower steel plate.

The bolt was tightened in increments of 50 lb•in. (5.7 N•m) by use of a dial-indicator torque wrench. At each torque setting, the tensile force applied by the bolt was measured. After the measurement at a torque of 250 lb•in. (28 N•m), the bolt was loosened. This sequence of operations was then repeated seven more times (for a total of eight torque cycles).

The measurement data show that the preload at each torque setting decreased from the first to the second cycle, then remained about the same through the fourth cycle, then fell on the fifth through eighth cycles. The overall average decrease in preload after eight cycles was 29.8 percent. The data can be interpreted as meaning that the threaded surfaces deteriorate after only four cycles.

The report concludes, among other things, that if cost is not an overriding consideration, it could be desirable to replace threaded fasteners after four torque cycles. Where replacement is not cost-effective, the torque setting could be increased (up to the maximum safe value) on the next torque cycle to compensate for the loss of preload at the previous setting. Therefore, experiments like this one should be performed on fasteners of various grades and materials to quantify the preload-reduction factors for many applications.

This work was done by Richard A. Akian of Rockwell International Corp. for **Marshall Space Flight Center**. *To obtain a copy of the report, "The Effect of Repeated Torquing on Bolt Preload and Torque Coefficients," Circle 56 on the TSP Request Card. MFS-29878*

Simulations of Three-Dimensional Flow With Separation

Navier–Stokes computations of flows over protruding fins are presented.

A report discusses numerical solutions of the Navier–Stokes equations for viscous supersonic flow over a fin protruding from a flat plate. Two types of configurations are considered: one with a wedge-shaped fin (sharp edge facing upstream), the other with a blunt (rectangular parallelepiped) fin. Only steady flows are considered: these include laminar flows and flows that are turbulent but otherwise steady in the mean. These computations were performed to study phenomena involved in separations of three-dimensional flows.

To prepare the reader for the subsequent discussion, some general concepts of separation of three-dimensional flow are first briefly reviewed. In particular, descriptions in terms of bubbles vs. free-vortex layers and open vs. closed separations are emphasized. The rest of the report is devoted to the discussion of the results of the computations. Various computations were performed, using the same number of grid points but changing the spacings of the computational grid to investigate the effects of grid resolution on the origin of the line of separation. Various shock strengths were used to study the so-called separated and unseparated boundary layer and to establish the existence or absence of secondary separation. The length of separation ahead of the blunt fin, bifurcation of a horseshoe vortex, and the accessibility of a closed-type separation were investigated. The usual interpretation of the flow field from previous studies and new interpretations arising from these simulations are discussed.

The numerical results demonstrate that in the case of the sharp fin, the resolution of the computational grid can affect the type of the separation: For the coarse grid, the separation is open type. As the grid near the leading edge is refined, the starting point of the open-type separation moves upstream, and eventually the separation becomes closed.

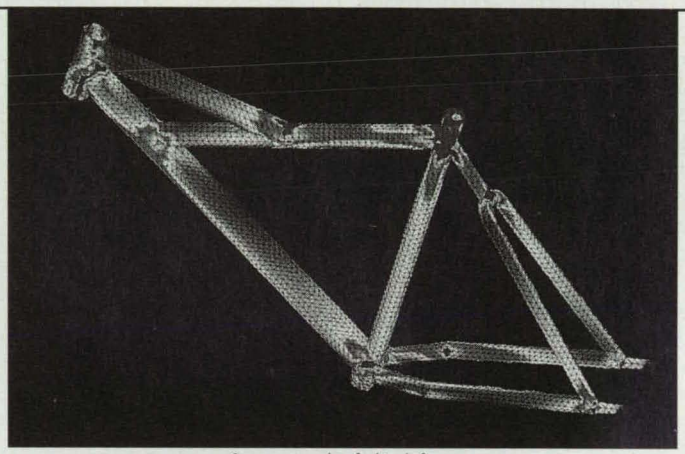
On the basis of computed surface-particle traces, no secondary separation was found in this study. A secondary oil-accumulation line observed in a previous experimental study is conjectured to be a demarcation between regions of high and low surface skin friction. A calculation with a 2° wedge angle shows no obvious line of convergent particle traces, and the turning angles of skin-friction lines are found to be smaller than the glancing shock angle. This is conventionally interpreted as an attached flow. However, in a close examination of the particle traces near the apex, it appears that the flow is separated, and the structure is topologically the same as that of flow field around the blunt fin.

The following conclusions are drawn from the computations for the blunt fin:

- The length of separation is about 5.2 D (where D = the thickness of the fin), compared with about 2.0 to 2.5 D for a hemicylindrical fin, and this agrees with experimental observations.
- Even though there is a "kink" in the pressure distribution, the main horseshoe vortex bifurcates into two, and there is no secondary separation under the main horseshoe vortexes. In this case, three vortexes are present. Therefore, one can conclude that the number of vortexes is not always an even number.
- For the case investigated, the separation point is connected to the inner (downstream) horseshoe vortex, rather than the outer (upstream) one. Four layers of fluid are entrained into three vortexes.
- The concept of a closed three-dimensional separated region being inaccessible is valid only in the limit of particles moving near the surface of the fin/plate body. The flow particles above the surface gain access to the separated region through the attachment node and the spiral nature of the separation. Indeed, there is no three-dimensional separation that is totally closed by a separation surface: there must be some fluid flowing in and some fluid flowing out. All three-dimensional separation can be characterized as vortex sheets of various kinds. In general, in the three-dimensional case, an attachment is not the reverse of a separation, or vice versa.

This work was done by Ching-Mao Hung of **Ames Research Center**. *Further information may be found in NASA TM-102266 [N90-13353], "Computation of Navier–Stokes Equations for Three-Dimensional Flow Separation."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
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Magnetostrictive Roller-Drive Stepping Motor

Advantages would include high torque, precision, and fail-safe braking.

Goddard Space Flight Center, Greenbelt, Maryland

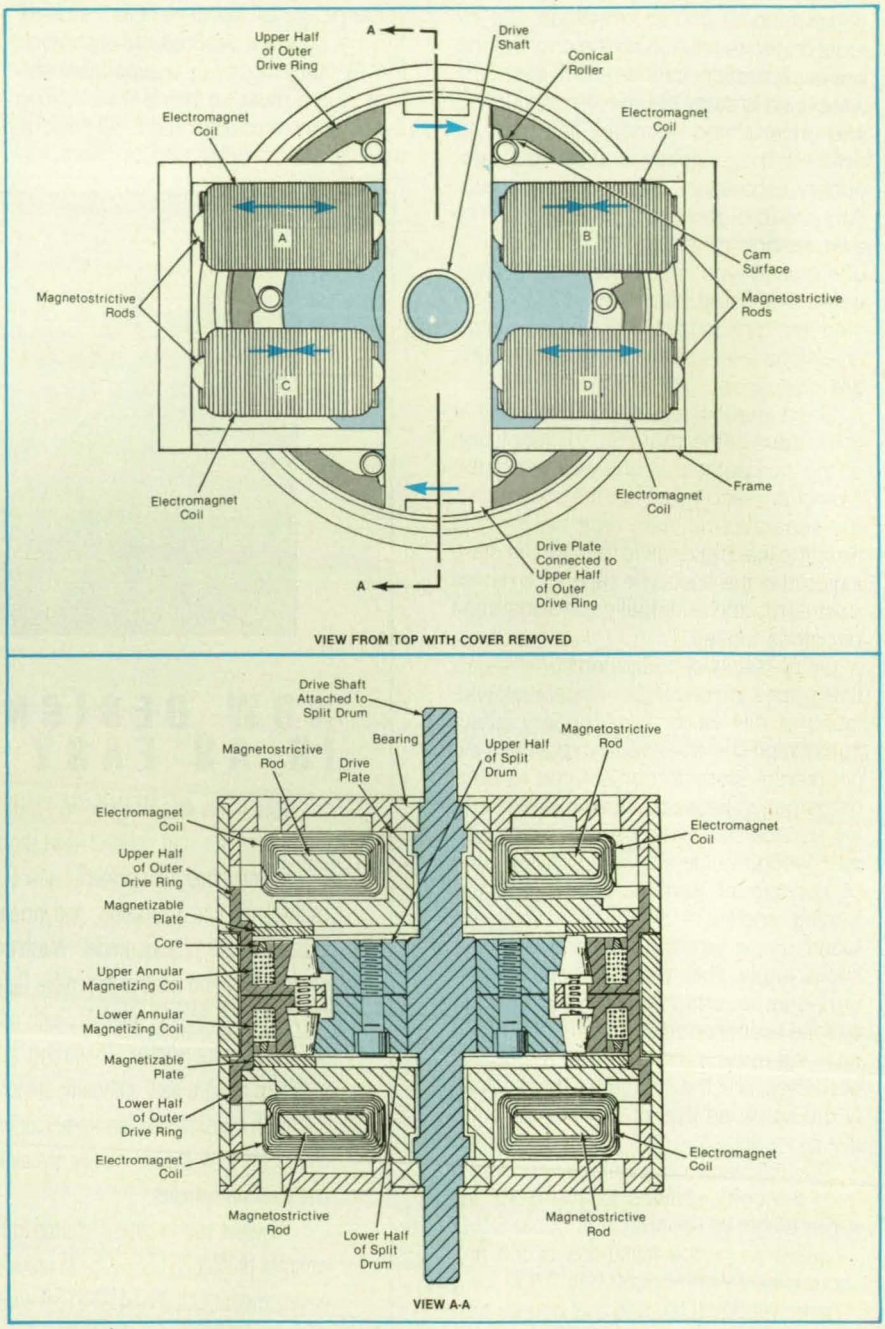
A proposed motor based on the magnetostrictive effect would provide stepped angular motion with angular increments of the order of 100 microradians. It could be driven to repeat the stepping cycle rapidly enough to achieve a maximum speed of about 20 rpm, would provide torque an order of magnitude greater than that of existing electric motors, and would brake itself when power is turned off. Thus, it would be particularly suitable for precise, high-torque, fail-safe-braking, direct drive of a robot joint, without the bulk and weight of an additional brake mechanism and gear train.

Eight electromagnets in groups of four near the ends of the motor (see figure) would be the sources of incremental angular motion. The cores of these electromagnets would be magnetostrictive rods, each of which would expand slightly when the electromagnet coil surrounding it was energized. To produce an incremental clockwise (as shown in the top view in the figure) rotation, coils A and D at the top end (and corresponding coils at the bottom end) would be energized, causing the magnetostrictive rods in them to expand slightly against a drive plate, which, in turn, would slightly compress the rods in unenergized coils B and C. The slight expansions of rods A and D would cause a slight clockwise rotation of the drive plate and of the upper half of an outer drive ring connected to the drive plate.

Cam surfaces on the inside of the upper half of the drive ring would force an upper set of conical rollers against similar cam surfaces on the outside of the upper half of a split drum attached to a drive shaft. Thus jammed between the upper halves of the drive ring and the split drum, the upper set of conical rollers would transmit clockwise torque and the incremental clockwise motion to the split drum and drive shaft.

A similar, lower set of conical rollers would transmit incremental counterclockwise motion when coils B and C (and the corresponding coils at the other end) were energized. Pairs of upper and lower rollers would be spring-loaded against their respective cam surfaces. While coils A and D were energized, a lower annular magnetizing coil would also be energized to pull a magnetizable plate upward against the slightly protruding lower ends of the lower conical rollers, thereby lifting the lower conical rollers out of contact with the adjacent cam surfaces. This would prevent the lower conical rollers from jamming in the counterclockwise-torque-transmitting position and interfering with the clockwise motion. A similar upper annular magnetizing coil and plate would be energized during an increment of counterclockwise motion to prevent interference by the upper conical rollers.

When no power was applied, the springs would force all sets of conical rollers



Magnetostrictive Rods in electromagnet coils would push against the drive plate, causing it to rotate slightly. This slight rotation would jam conical rollers between cam surfaces on the outer drive ring and the split drum, so that the rollers would transmit the rotation to the drum.

against their respective cam surfaces. Thus, any attempt to rotate the shaft clockwise or counterclockwise would be desisted by jamming of the lower or upper rollers, respectively. An increase in the applied torque would cause tighter jamming, with consequent increased resistance to turning.

This work was done by John M. Vranish of **Goddard Space Flight Center.** *For further information, Circle 8 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addresses to the Patent Counsel, Goddard Space Flight Center [see page 20]. Refer to GSC-13369.

Electrostatically Enhanced Vortex Separator

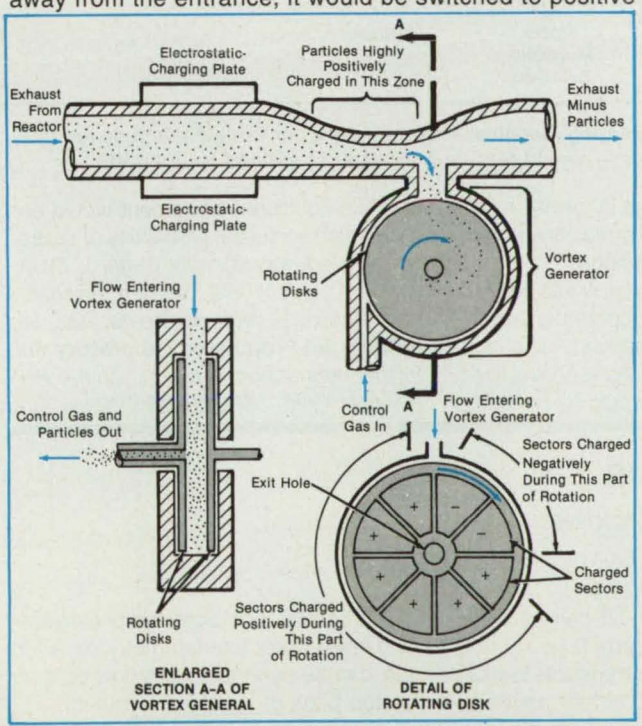
Small particles would be removed from gas flowing at high pressure.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed device would remove fine particles (e.g., fly ash) from the high-pressure exhaust gas of a chemical reactor. Gas without particles would then be released to the atmosphere.

The device (see figure) would effect a combination of electrostatic and vortex separation. The exhaust duct would narrow just upstream of a vortex generator, and just upstream of this constriction, plate electrodes on the sides of the duct would induce positive electrostatic charges in the particles.

Sectors of rotating disks on the sides of the vortex generator would be charged during part of the rotation in which those sectors passed by the entrance to the vortex generator. This would draw the positively charged particles into the vortex generator while the main flow of exhaust gas would continue along the exhaust duct. As each sector moved away from the entrance, it would be switched to positive



Negatively Charged Sectors on rotating disks in a vortex generator would attract positively charged particles from the main stream of exhaust gas. The electrostatic charge would thus enhance the particle-separating action of the vortex.

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charge to repel the particles. A small flow of control gas would carry the particles thus repelled out of the vortex generator through a hole along the axis of rotation.

The control gas and particles would pass through a pressure reducer, and the particles would be collected at atmospheric pressure. The mainstream exhaust gas would pass through a different pressure reducer before being vented to the atmosphere.

This work was done by Earl R. Collins of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 57 on the TSP Request Card.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

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1201 East California Boulevard
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Refer to NPO-18127, volume and number of this NASA Tech Briefs *issue, and the page number.*

Miniature Gas-Circulating Machine

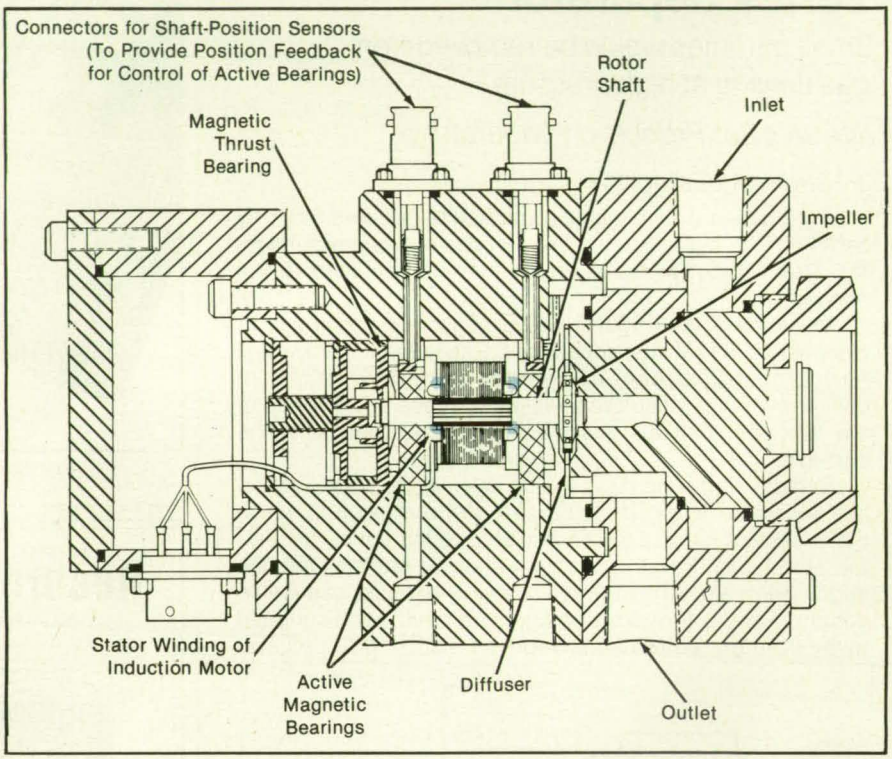
Noncontact bearings would suppress wear and contamination.

NASA's Jet Propulsion Laboratory, Pasadena, California

The figure illustrates a preliminary design of a proposed gas-circulating machine that would consist essentially of a centrifugal pump driven by an induction motor. The machine would be used to circulate helium (or possibly hydrogen or another gas) in a regeneration sorption-compressor refrigeration system aboard a spacecraft. Provided that the cost per unit could be reduced substantially, the machine might prove useful in terrestrial applications in which long life, reliability, and low contamination are essential.

Under the design operating conditions, the machine would pump helium from an initial pressure of about 600 psi (4.1 MPa) through a pressure rise of 3 to 10 psi (21 to 69 kPa) at a mass-flow rate of 0.25 to 0.85 g/s. The centrifugal impeller would have a diameter of 1.27 cm (0.5 in.) and would turn at 1,500 revolutions per second. The machine would consume 1 to 50 W of power, operating with an overall efficiency of 15 to 20 percent. The overall mass of the machine would be about 1 kg.

The motor would be of the induction type, which would last long and generate little, if any, contamination because there would be no brushes to wear. The rotor part of the motor would be a longitudinally serrated, magnetically soft integral part of the shaft that supports the centrifugal impeller. The rotor would be supported laterally on active magnetic or gas journal bearings and longitudinally by passive magnetic or gas thrust bearings. Thus, except during startup transients in the case of gas bearings, there would be no bearing contact and no wear, and the longevity, reliability, and cleanliness of the machine would be enhanced correspondingly.



The **Miniature Gas-Circulating Machine** — essentially a centrifugal pump driven by an integral induction motor — would feature noncontact bearings for long life.

Active magnetic bearings would be preferred under the design operating conditions. The only major disadvantage of active magnetic bearings is that a control system and power supply would be needed, and this additional equipment would entail a small additional probability of failure.

This work was done by Walter L. Swift, Javier A. Valenzuela, Herbert Sixsmith, and William E. Nutt of Creare, Inc., for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 11 on the TSP Request Card. NPO-18486*

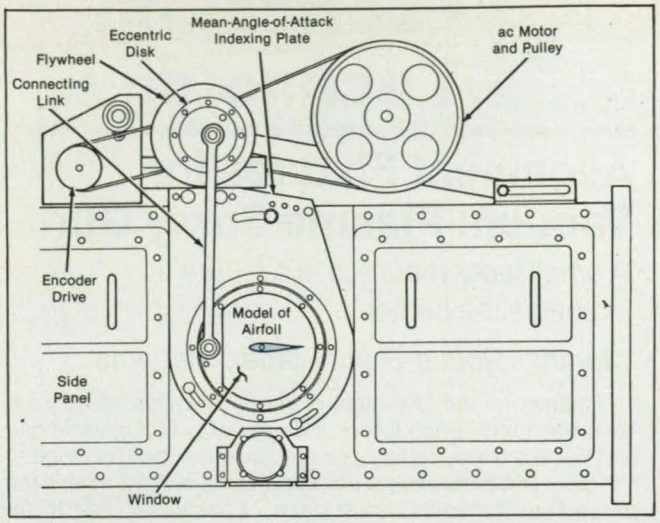
Visualizing Dynamic-Stall Airflows

Airfoils are supported and manipulated by viewing windows.

Ames Research Center, Moffett Field, California

A new wind-tunnel apparatus facilitates experiments on airfoils undergoing dynamic stall. Dynamic stall occurs when an airfoil is pitched rapidly past the static stall angle. In dynamic stall, lift can become greater than that in steady flow.

The apparatus makes it possible to visualize flow on oscillating airfoils nonintrusively. Stroboscopic Schlieren photography and holographic interferometry, for example, can be used to record flow patterns as the pitch of an airfoil is varied.



Schematic shows an airfoil mounted in the compressible, dynamic-stall wind tunnel.

The key to unobstructed visualization is the method for mounting a scale-model airfoil in the apparatus. Previously, the massive airfoil support structure—needed to withstand the large dynamic loads—blocked important parts of the airflow from observation. In the new apparatus (see figure), the mounting structure is also the viewing window: the airfoil is pin-mounted between two optical-quality glass windows. The windows are oscillated simultaneously, giving an unobstructed view of the complex flow around the pitching air-foil.

The mean angle of attack and the amplitude of oscillation can be adjusted continuously. The angle-of-attack assembly supports a motor-and-flywheel system. Eccentric disks in the flywheel establish the amplitude of oscillation.

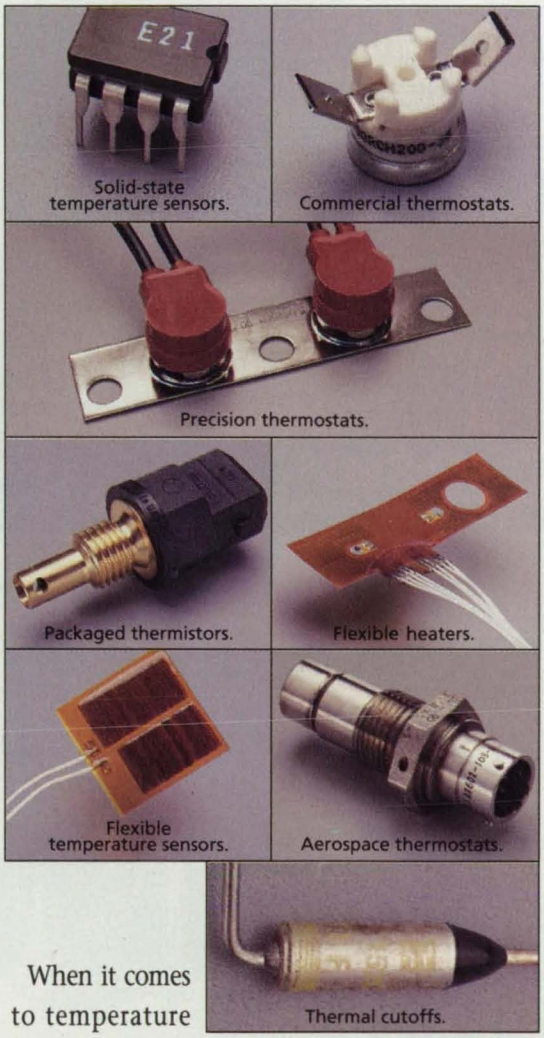
Tapered pins in the glass windows hold the airfoil. The windows are 15.2 cm in diameter and 2.54 cm thick. They rest in magnesium frames on bearing races. A sliding seal prevents outside air from leaking into the test section.

The apparatus has yielded the first images of unsteady compressible flow over dynamically staking airfoils that accurately represent instantaneous vortex strength. The images show density gradients at the instant the photographic image is taken, unlike images obtained using older visualization methods based on the flow of smoke or hydrogen bubbles, which show only what the vortex has done to the flow in question up to the time of the photograph.

This work was done by L. Carr of **Ames Research Center** *and M. Chandrasekhara of the Naval Postgraduate School. Further information may be found in AIAA paper 89A-25511, "Design and Development of a Compression Dynamic Stall Facility.'*

Copies may be purchased [prepayment required] from AIAA Technical Information Service Library, 555 West 57th Street, New York, New York 10019, Telephone No. (212) 247-6500. ARC-12470

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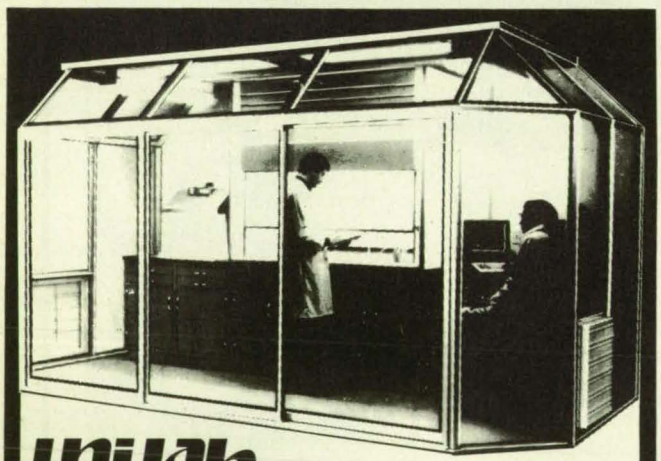
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Fabrication Technology

Alignment Fixtures for Vacuum-Plasma-Spray Gun

A small laser mounted in a fixture indicates the center.

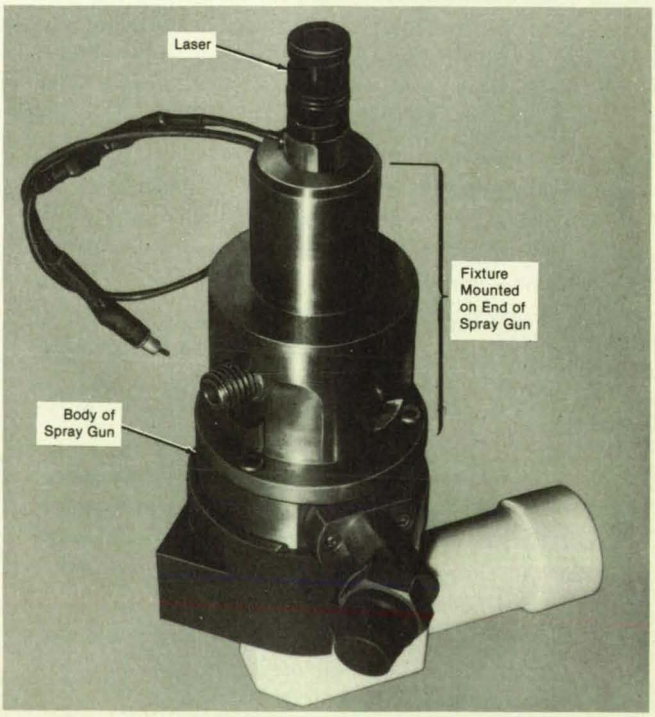
Marshall Space Flight Center, Alabama

Fixtures for the alignment of vacuum-plasma-spray guns have been built. Each fixture is designed to fit a specific gun and holds a small, battery-powered laser on the centerline of the gun. The laser beam projects a small red dot where the centerline intersects the surface of the workpiece to be sprayed.

The fixture consists basically of two concentric sections of thick-walled aluminum tube, one of which fits onto the cylindrical end of the gun, the other of which holds the laser (see figure). Fixtures have been built for spray guns of various sizes and shapes. The inner diameter of the outer tubular section is the same in all the fixtures so that the same laser can be used in any fixture.

This work was done by William H. Woodford, Timothy N. McKechnie, Christopher A. Power, and Ronald L. Daniel, Jr., of Rockwell International Corp. for **Marshall Space Flight Center.** *For further information, Circle 2 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 20]. Refer to MFS-29871



The **Fixture Holds a Small Laser.** After the laser beam has been positioned on the surface of the workpiece, the fixture is removed form the gun and spraying can proceed.

Cheaper Fabrication of Tube-Wall Components

Tubes are pressed together in mandrels to fill gaps.

Marshall Space Flight Center, Alabama

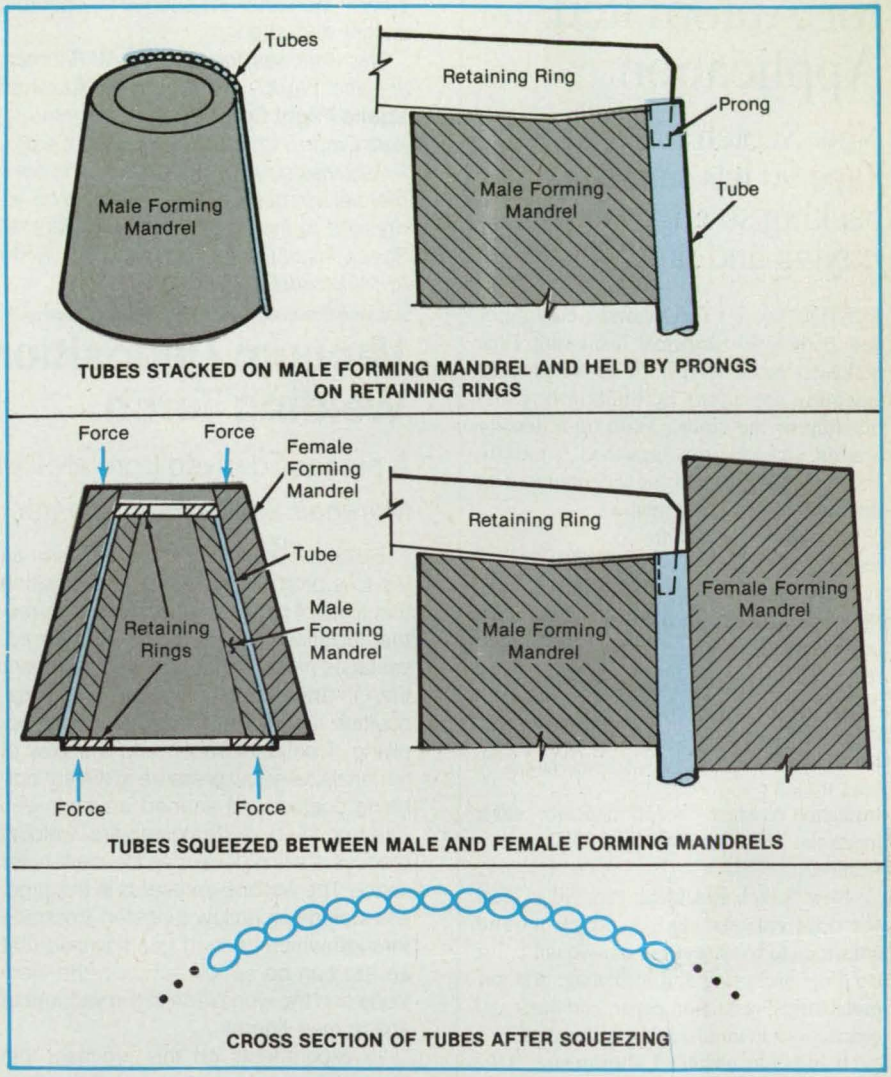
A relatively inexpensive method of forming metal tubes into a wall component (e.g., the wall of a rocket nozzle or combustion chamber) has been devised. Previously, tubes were selected, by use of a computer, from a large inventory to account for variations among their precisely measured diameters. Then the tubes were stacked in the desired configuration and subjected to a long brazing procedure to bridge gaps between them.

In the new method, one can initially select ordinary, imprecisely dimensioned tubes that have passed both a pressure test and inspections for wall thickness and surface imperfections, and the tubes are bonded to each other in a shorter, simpler procedure. The method eliminates the need for progressive die forming and the attendant inspections after forming steps. The method may also be applicable in the fabrication of heat exchangers and other unitary assemblies of tubes.

A complete set of tubes is stacked on a male forming mandrel (see figure). The tubes are held by pronged retaining rings at both ends. A female forming mandrel is then lowered onto the tubes. Both inner and outer forming mandrels are coated with a film of boron nitride, yttrium oxide, molybdenum disulfide, or other dry lubricant so that the tubes can slide against them easily.

The assembly of tubes and forming mandrels is squeezed axially in a press. This deforms the tubes, flattening them into roughly oval cross sections and eliminating the gaps between them. The forming mandrels may be fluted to impose specified curvatures on the outer surfaces of the formed tubes. After this forming process, the tubes are removed from the forming mandrels. The tubes are subsequently restacked on a suitable holding mandrel in the same relative positions as in the forming mandrels, then brazed or diffusion-bonded together.

The forming mandrels are expected to wear minimally because of the lubricant coating. In the event of wear, surfaces of the mandrels can be remachined several times.



Tubes Are Arranged on the male forming mandrel, retained by prongs at both ends, then squeezed between the male and female mandrels. The tubes yield, filling the gaps between them.

This work was done by Daniel A. Bales and James R. Joyce of United Technologies Corp. for **Marshall Space Flight Center**. *For further information, Circle 46 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 20]. Refer to MFS-28645.

Machined Structural Panels With Integral End Fittings

Unitary structural components would have large strength-to-weight ratios.

Marshall Space Flight Center, Alabama

Flat, cylindrical, or otherwise-shaped unitary machined corrugated metal panels (see figure) would be used as structural skins, according to a proposal. The machined plates would offer advantages over such conventional lightweight structural components as formed corrugated sheets, composite panels, and honeycomb panels. The proposed machined plates would include integrally machined end fittings and therefore would be lighter, less prone to failure, and easier to design and analyze. In addition, they would offer greater stiffness. No additional stringers or frames would be needed for reinforcement.

The fabrication of a panel of the proposed type could include, for example, machining on a computer-numerical-control end mill to form pockets of crossed corrugation. As in a formed panel, the corruga-

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New Scotch™ Electrical Tape 90 has saturated backing so edges resist fraying and raveling

AUSTIN, Tex. — The saturated backing of new Scotch 90 Electrical Insulating Tape makes it more adaptable to automated assembly operations by limiting fray and raveling of the cloth. With high density woven strands, the tape has a tensile strength of 150 lbs/in, in accordance with the ASTM D 1000 test method.

The white glass cloth features a pressure sensitive rubber thermosetting adhesive that offers superior absorption of electrical insulating resins and varnishes. Insulation resistance is 250 megohms and it meets the MIL-I-15126F (type GFT) specification.



Saturated backing helps keep the tape edges from fraying.

New Scotch Electrical Tape 90 is ideal for applications such as stick wound coils/transformers and bobbin-wound coils; banding, anchoring and insulating; and terminal strips, insulation paper, end turns and connections in motors and transformers.

It is Underwriters Laboratories (UL) Recognized for use at temperatures not exceeding 155° C per UL Standard 510, UL File Number E17385, Guide-OANZ2.

To achieve maximum solvent resistance and holding performance, Scotch Electrical Tape 90 thermosetting can be achieved at one of the following cycles: One hour at 150° C, two hours at 135° C, or three hours at 120° C.

New Scotch Electrical Tape 90 joins the 3M family of conformable glass cloth tapes, with a temperature class of 130° C to 180° C and insulation resistance of 250 megohms. Electrical Grade Glass Cloth Tapes 27, 79, 69 and 90 are all printable.

For more information about Scotch Electrical Tape 90, contact an authorized distributor or write: 3M Electrical Specialties Division, Building 130-3N-56, 6801 River Place Blvd., Austin, Texas 78726-9000, or call (800) 328-1368.

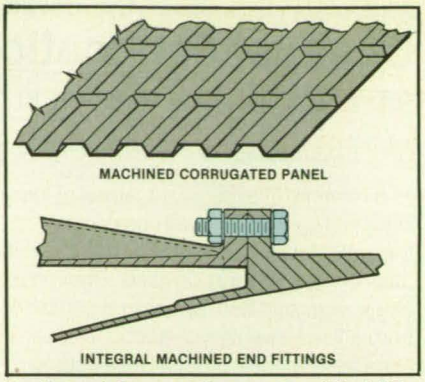
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tions would stiffen the remaining material. End fittings for welded or bolted connections would also be machined in the panel. The panel could thus be attached to adjacent panels with minimal extra hardware. The end fittings could be smoothly blended with the panel and shaped for optimum weight and strength.

This work was done by John W. Redmon, Jr., and Patrick R. Rogers of **Marshall Space Flight Center**. *For further information, Circle 3 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 20]. Refer to MFS-28667.



Pockets of Crossed Corrugation Would Be Machined into a panel. Integral end fittings for assembly to adjacent panels could be smoothly contoured.

Vacuum Deposition From a Welding Torch

A process derived from arc welding produces films of high quality.

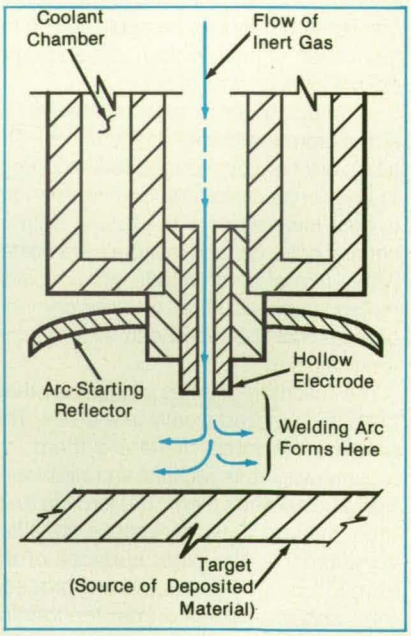
Marshall Space Flight Center, Alabama

Research on welding in outer space has led to a promising method of depositing thin films of metal on substrates in terrestrial facilities. The method offers the advantages of fast deposition (perhaps faster than in any currently available vapor deposition technique), the possibility of applying directional impetus to the flow of materials, very low pressure at the surface being coated, and an inert environment.

A modified gas/tungsten-arc welding process is being developed for use in outer space. The welding apparatus in this process includes a hollow tungsten electrode through which an inert gas flows so that an arc can be struck between the electrode and the workpiece in the vacuum of space (see figure).

In experiments on this process, thin films of the same material as that of the workpiece were found to be deposited on surfaces near the workpiece. Accordingly, the experiments were modified, replacing the workpiece with a variety of metal sources. A variety of feed gases and substrates were used in the experiments. For example, in one case, the source material was a Ni/Cr/Fe alloy, and the substrate was glass. The film deposited on the substrate consisted of Cr, Ni, and Fe — the constituents of the source alloy, although in proportions different from those of the alloy. The differences are attributed to differences among the vapor pressures of the Cr, Ni, and Fe constituents at the melting temperature of the alloy (about 1,600 °C).

In similar experiments, coats of copper, niobium, aluminum, and nickel were also deposited on glass and steel. All coats had smooth surfaces, were thin but covered the substrates completely, adhered well to the substrates, and had the colors of the corresponding source materials. In a different experiment, a copper/niobium film was deposited on graphite fibers in a loose bundle. The thin coat surrounded each fiber. The coat may be useful in obtaining a stronger bond between the fibers and other materials — for example, the coat may act as a wetting agent when bundles or laminates of fibers are imbued with resin to form a fiber/matrix composite material.



The **Modified Gas/Tungsten-Arc Welding Torch** is directed at a target material in a vacuum chamber. Vaporized target material is carried by the flow of inert gas and is deposited on a substrate near the arc. More than one torch and target could be used to alter the composition of the deposited film with depth.

This work was done by R. M. Poorman of **Marshall Space Flight Center**. *Further*

information may be found in NASA TM-103542 [N91-27330], "Vacuum Vapor Deposition — A Spinoff of Space Welding Development."

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 20]. Refer to MFS-28652.

Improved Heat Treatment of Steel Alloy 4340

Significant increase in hardness is achieved with minimal deflection.

Langley Research Center, Hampton, Virginia

Steel alloy 4340 has been an integral part of the construction process, used in buildings, aircraft, bridges, and other applications in which strength and durability at relatively low cost are required. Recently, 4340 steel has been considered for use in the construction of armorplate for military aircraft. Because of the extremely high hardenability of this steel, it affords exceptionally effective protection for passengers as well as for an aircraft itself. However, an effective method of heat-treating 4340 steel to desired hardness for certain applications without deflection did not exist. A new process developed at NASA Langley Research Center imparts maximum hardness with only slight deflection, which is easily pressed out. The new process takes significantly less time than do prior heat-treatment processes.

The prior standard heat treatment of 4340 steel began with normalization at 1,600 °F (871 °C) followed by quenching in agitated oil, followed by heating to 1550 ± 25 °F (843 ± 14 °C) for 45 minutes to 1 hour per inch of thickness (0.4 hour per centimeter of thickness). The steel was then tempered at 400 to 1,100 °F (about 200 to 600 °C) for 1 to 2 hours, according to the dimensions of the mass being treated, to relieve stresses and prevent warping or cracking.

The new method involves placing the steel plate directly in the furnace and heat-treating for 45 minutes at 1,520 °F (827 °C). The plate is then quenched in slowly moving oil (not agitated) for 3 to 5 minutes to reduce stresses. Any deflection is then pressed out. Hardness readings taken at this stage in a demonstration of the process were around 55 to 60 R/C, much higher than any previous levels obtained by NASA, which were in the 33 to 45 R/C range. The alloy plate is then tempered at 450 °F (232 °C) for 1 hour to relieve stresses. After cooling, the hardness remains essentially the same.

Possible uses of 4340 steel heat-treated in the new way include new and improved bulletproof vests for military and police personnel and armor for bulletproof automobiles for military, police, diplomatic, and private users. It could also be used in such other military land vehicles as tanks and in both military and civilian aircraft. Lighter armorplate would enable land vehicles and aircraft to attain greater speed and maneuverability, consume less fuel (or, alternatively, operate over longer ranges), and afford better protection from snipers or terrorists.

This work was done by Lawrence B. Cooper of **Langley Research Center**. *No further documentation is available.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 20]. Refer to LAR-14291.



For More Information Circle No. 574

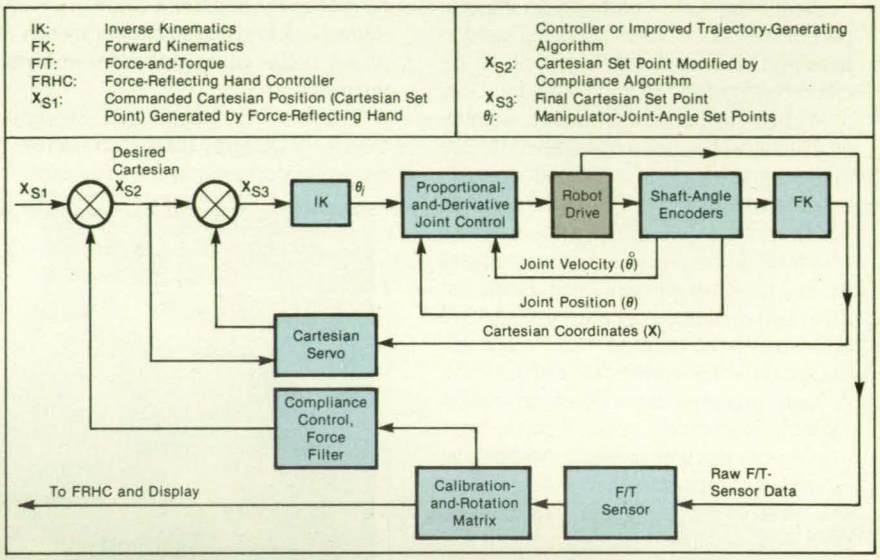
Generating Smooth Motions for Robotic Manipulators

Velocities are computed as sinusoidal functions of positions during acceleration and deceleration.

NASA's Jet Propulsion Laboratory, Pasadena, California

In an improved method for generating the trajectory of a robotic manipulator, each straight-line segment of the trajectory is composed of a constant-velocity main portion sandwiched between smooth acceleration at the start and smooth deceleration at the finish. The algorithm that implements this method computes the velocity in each accelerating portion as a sinusoidal function of position along the line. This kind of motion was chosen for two reasons: It closely approximates the motion of a human hand along a straight-line trajectory, and it provides very smooth transitions between the constant-velocity portion and the accelerational and decelerational end portions.

Heretofore, typical trajectory-generating alogorithms have been based on polynomials in position-vs.-time state space. The new algorithm yields smoother motions. The algorithm performs its computations in the Cartesian coordinates of the workspace. The operator or a higher-level



This **Position-Servocontrol Loop**, which is closed in the Cartesian coordinates of the workspace, can be used to implement force-reflecting hand control or the improved method of generating trajectories with smooth motions.

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planning computer program sets three parameters: the total distance to be traveled along the specified straight-line segment, the velocity in the constant-velocity main portion, and the length of the accelerational and decelerational end portions. The algorithm then computes those incremental changes of position along the Cartesian axes that, when implemented at the measurement-sampling-and-command rate of the robotic system (typically, 1 kHz), result in the desired velocity-vs.-position profile.

The figure illustrates a position-servocontrol loop that is closed in the Cartesian workspace. This subsystem can be used in conjunction with a force-reflecting hand controller to implement manual control, or with a computer running the improved trajectory-generating algorithm. Cartesian position commands are supplied by the algorithm or by the hard controller. The actual Cartesian coordinates of the robotic manipulator are computed via a forward kinematic transformation from the manipulator joint angles. The errors (the differences between the commanded and actual Cartesian coordinates) are converted via an inverse kinematic transformation into manipulator-joint-angle set-point commands.

The improved trajectory-generating algorithm can also be combined with an active-compliance algorithm by use of this servocontrol loop. Two kinds of active compliance have been tested thus far: spring compliance, in which the deviation in the position of the end effector of the robot is proportional to the sensed force; and integrating compliance, in which the velocity of the end effector is proportional to the force sensed in the corresponding direction.

This work was done by Antal K. Bejczy and Zoltan F. Szakaly of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 61 on the TSP Request Card.*
NPO-18377

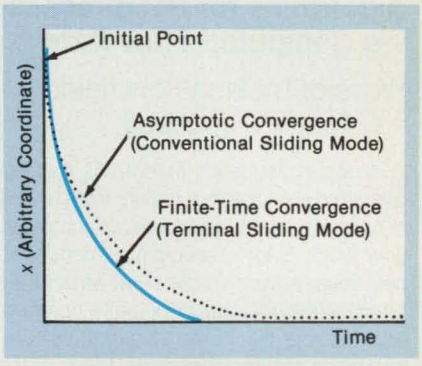
Terminal Sliding Modes in Nonlinear Control Systems

Systems would converge to equilibria in finite times.

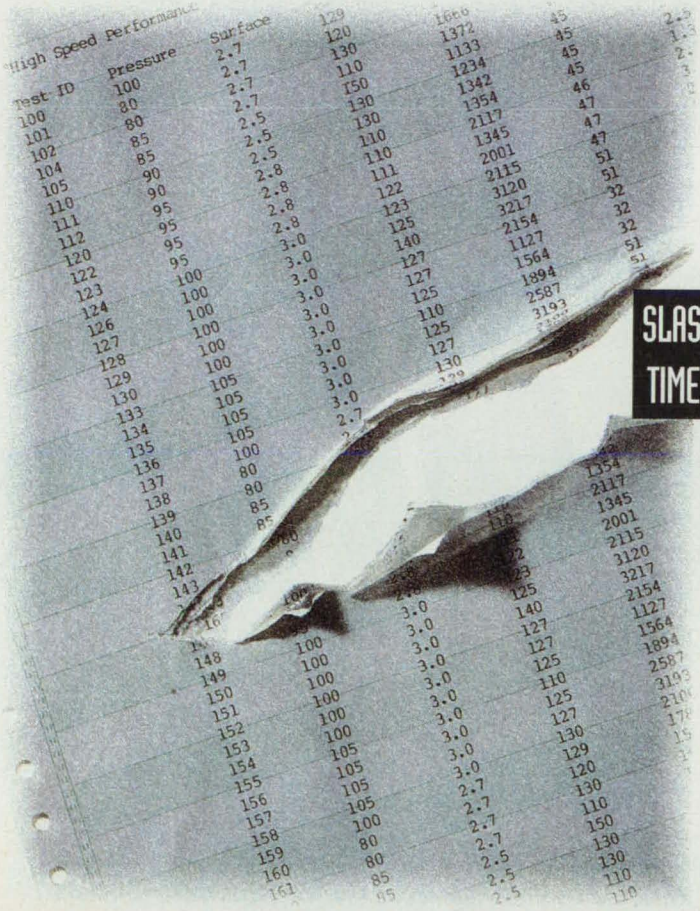
NASA's Jet Propulsion Laboratory, Pasadena, California

Control systems of a proposed type called "terminal controllers" would offer increased precision and stability of robotic operations in the presence of unknown and/or changing parameters (e.g., changing frictional forces, payloads of uncertain weight, workpieces of uncertain dimensions). Systems of this type would include special computer hardware and software that would implement novel control laws that involve terminal sliding modes of motion: The closed-loop combination of a robot and a terminal controller would converge, in a finite time, to a point of stable equilibrium in an abstract space of velocity and/or position coordinates applicable to the particular control problem.

The terminal sliding modes would be enforced by incorporating nonlinearities into the control laws. These nonlinearities would



In a Terminal Sliding Mode, a system would converge from an initial point to a point of equilibrium (represented here by the point $x = 0$) in a finite time. In a conventional system, the convergence is typically asymptotic.





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be structured as terminal attractors, which have been a subject of considerable interest in research on artificial neural networks. In addition to finite-time convergence (as contrasted in the figure with asymptotic convergence of typical conventional sliding-mode controllers), the proposed control systems would offer the possibility of operation without the chatter that is caused by rapid switching between different control modes. Such switching is often incorporated into conventional control laws to impart robustness in the presence of uncertainties in parameters.

Terminal controllers that enforce finite-time convergence of a simple one-dimensional system to equilibrium have been investigated theoretically. It was found that performance would be improved significantly through the elimination of high-frequency control switching. The dependence of the stability of terminal sliders upon rates of change of uncertainties in parameters (rather than on the magnitudes of the uncertainties) was found to result in increased robustness of control in the presence of the uncertainties. Reliability was found to be enhanced through elimination of the interpolation regions that are used in conventional control. The attainable precision was also found to be greater with terminal than with conventional control.

This work was done by Subramanian T. Venkataraman and Sandeep Gulati of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 17 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 20]. Refer to NPO-18584.

Books and Reports

These reports, studies, handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Algorithms for Postprocessing Computed Flow Data

Ways of making flow fields visible are discussed.

A paper discusses algorithms that are used to make visible displays from arrays of numerical data that represent computed flow fields. Such displays are intended to help researchers discern flow structures. The displays include, principally, contours and particle traces on two-dimensional- and three-dimensional grids. Many of the algorithms that generate these plots have been implemented in the PLOT3D computer program.

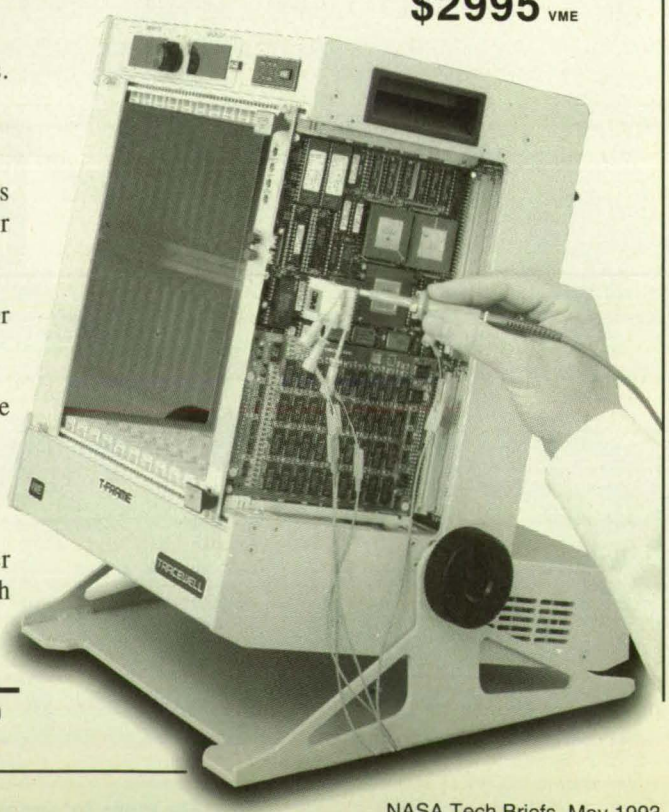
Contouring is used to display scalar functions. Contour lines and bands can show values of functions on two-dimensional surfaces, while contour surfaces that are curved in three dimensions serve as three-dimensional analogs of contour lines. Colors and Gouraud shading enhance the presentation of values and ranges of values of functions. The generation of contours on cross-sectional surfaces that cut through arbitrary three-dimensional grids at arbitrary angles is difficult, but it can be done by use of a combination of techniques that includes the technique for finding a three-dimensional contour surface and the technique for plotting contours on an arbitrary two-dimensional grid.

Particle traces are the computational analogs of smoke or dye injected into experimental flows. Particle traces include dots or bubbles, lines, ribbons (formed by lines traced from two nearby starting points), and sheets. These plots are generated by interpolating the velocity field to the evolving location of a given particle and computing the evolution of this location by integrating the velocity over time. The part of the particle-tracing task that involves the most computation is the transformation between the coordinates of the physical space and the coordinates of the computational space in which the differential equations of flow are integrated numerically.

One of the primary purposes of graphical analysis of computed flows is to locate and identify such features as shock waves, vortices, and regions of separated flow. While these features can usually be identified from plots of various functions, the search of a solution, especially one com-

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puted on a multiple-block grid about a complicated object, consumes much time. Identification of a feature may be difficult because of poor resolution or because the grid is not conveniently aligned with the feature. The report addresses these issues by describing what quantities can be plotted and which of the plotting techniques described above can be used effectively to identify selected features.

The report presents some conclusions, including the following:

* The slowness of current postprocessing algorithms places limits on ability to understand complicated three-dimensional flows. Faster algorithms and new, more-powerful graphical computer workstations will help overcome these limits.
* Current postprocessing algorithms are of some help in identifying such features as vortices, shock waves, and separation lines, and the algorithms reduce the need for intensive, interactive examination of computed flow fields. However, the algorithms do not yield precise descriptions of the features, and the application of the algorithms is not automatic: the researcher must choose such parameters as contour levels and starting points of particle traces.

This work was done by Pieter Buning of ***Ames Research Center.*** *To obtain a copy of the report, "Numerical Algorithms in CFD Post-Processing," Circle 83 on the TSP Request Card. ARC-13153*

Evaluating Risk of Failure With Limited Information

In a probabilistic approach, uncertainty is treated quantitatively.

A report describes probabilistic failure assessment (PFA), a methodology for quantitatively evaluating the risk of failure of a system about which limited information is available. Such information typically consists of limited experience from tests or service and results of engineering analyses of failure modes.

In PFA, the uncertainties of engineering analysis, resulting from vague or uncertain information about environments, behavior of materials, accuracy of modules used in analysis, and other such governing parameters, is treated quantitatively within a statistical structure, in which a failure risk distribution is defined. The failure risk distribution can be modified to reflect available test or service experience using the Bayesian statistical procedure of PFA.

PFA was developed for application to spaceflight systems for sufficient testing of hardware to ensure reliability is not feasible. However, it must be ascertained that critical failure modes are extremely unlikely to occur during service.

PFA can be applied to any failure mode that can be described by quantitative models of the physics and mechanics of the failure phenomena. Examples of such failure phenomena include fatigue crack in initiation or propagation in structures, leakage of seals, wear in bearings, and erosion of arcjet thrustor cathodes. The report describes PFA and applications to fatigue of rocket engine components.

The major steps of PFA include probabilistic modeling of failure phenomena based on engineering analysis to consider the impact of available test or service experience on the predicted failure risk distribution.

These steps are carried out for selected failure modes identified by such procedures as Failure Modes and Effects Analysis (FMEA). Monte Carlo simulation is used to generate the information on which the predicted failure risk distribution is based.

This work was done by N.R. Moore, D.H. Ebbeler, M. Creager, L.E. Newlin, and S. Sutharshana of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "An Improved Approach for Flight Readiness Certification — Methodology for Failure Risk Assessment and Application Examples," Circle 89 on tthe TSP Request Card. NPO-18389*

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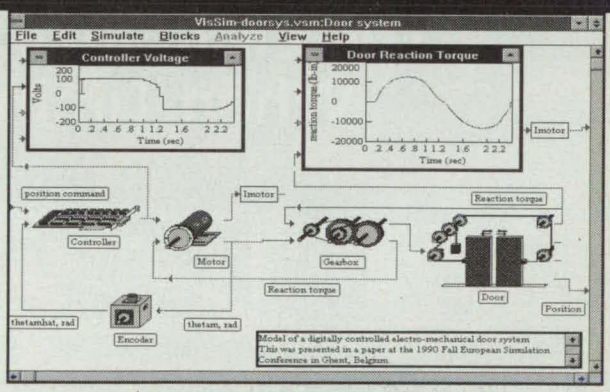
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For More Information Circle No. 568

Neuromorphic Learning From Noisy Data

A neurocontroller was found to exhibit noise-filtering properties.

Two reports present a numerical study of the performance of a feedforward neural network trained by a back-propagation algorithm in learning continuous-valued mappings from data corrupted by noise. Two types of noise were considered: plant noise (which includes both sensor and actuator noise), which affects the dynamics of the controlled process and data-processing noise, which occurs during analog processing and digital sampling of signals. This study was performed with a view toward the use of neural networks as neurocontrollers (1) to substitute for, or enhance, the performances of human experts in controlling mechanical devices (e.g., automobiles, small powerboats, and machine tools) in the presence of sensor and actuator noise and (2) to enhance the performances of more-conventional digital feedback electronic process controllers in noisy environments (e.g., in chemical plants and oil refineries).

It has already been demonstrated that neural networks have the potential for fast, robust, and reliable implementation of learned mappings, and are, therefore, well suited for real-time feedback control. However, the effect of noise (which is always present in a feedback control system) was unknown. This study includes an analysis of the effect of noise and proposes to maximize performance in the presence of noise by a selective sampling of the set of training data.

The analysis was conducted for a specific example of real-time control: a multilayer neural network in a feedback control system assigned to control a horizontal applied force to stabilize the horizontal position of a one-dimensional cart and to maintain near vertical the orientation of a pole hinged to the cart. The learning performance was found to depend essentially on the degree of embodiment of the control law in the set of training data and on the degree of uniformity of the probability-density function of the data presented to the network during a training sequence. Embodiment and uniformity were found to depend on the number of sampled motions of the cart-pole system, the observation time, the rate of sampling, and the scaling of the control signal. An error function was introduced to help select optimum values of these parameters.

It was found that when a control law was corrupted by noise, the fluctuations of the training data biased the probability-density function of the sequence of training data. In general, a neural network can develop a good internal representation of a mapping and be useful as a neurocontroller only when the effect of noise on the uniformity of the training data sequence is minimized and the degree of embodiment of the mapping in the training data set is maximized.

As a demonstration, the multilayer neural network in the cart-pole system was trained, via back propagation, with noisy data, to extract both linear and nonlinear control laws. The neurocontroller was found to filter plant noise and data-processing noise from the training data, and, in this application, it operated more smoothly than did the teacher in the presence of plant noise.

This work was done by Walter C. Merrill of **Lewis Research Center** *and Terry Troudet of Sverdrup Technology, Inc. To obtain a copy of the report, "Neuromorphic Learning of Continuous-Valued Mappings from Noise-Corrupted Data," Circle 89 on the TSP Request Card. Further information may be found in NASA TM-4176 [N90-25607], (also called "Neuromorphic Learning of Continuous-Valued Mappings From Noise-Corrupted Data: Application of the Real-Time Adaptive Control").*

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Monatomic Oxygen Makes Materials Biocompatible

Modified surfaces encourage the growth of cells.

Lyndon B. Johnson Space Center, Houston, Texas

Treatment with monatomic oxygen activates the surfaces of biomedical and biotechnical materials without adversely affecting the properties of the bulk and without introducing toxic or otherwise dangerous solvent residues. The treatment can be used to create a carpetlike texture that greatly increases surface area and encourages cells to adhere and grow. On silicone tubing for vascular implants, for example, a carpet surface improves acceptance by the body. On polymer beads and vessels, such a surface increases the effectiveness of growing, storing, and separating cell cultures.

Alternatively, treatment with monatomic oxygen can be used to change the surface chemistry by adding reactive functional groups to a chemically inert surface. The material can then be subjected to a variety of wet chemical reactions that would otherwise be ineffective.

A carpet surface is produced by exposing materials to a flow of monatomic oxygen (instead of the usual molecular oxygen). Monatomic oxygen is relatively abundant in the upper atmosphere of the Earth, and thus treatments can be carried out on Space Shuttle missions. Alternatively, one of several high-energy neutral-beam devices can be used in terrestrial laboratories. In some cases, a commercial plasma sputter-etching machine, which provides reactive oxygen atoms and radicals in combination with ions, can be used.

If the interior of a tube is to be given a carpet surface, the polymer should be treated as a flat sheet, then formed into the tube. Another possibility is treating the exterior of the tube, then turning it inside out. An irregularly shaped piece can be rotated on a goniometer while it is exposed to the flux of monatomic oxygen flux through a slit. Each element of surface is thus given a known dose at perpendicular incidence.

If only chemical modification, without carpet texture, is wanted, a material can be exposed to monatomic oxygen in a thermal gas environment. Either a commercial plasma asher with a Faraday-cage insert or a commercial flowing-afterglow device can be used. The thermal gas inhibits the formation of a carpet surface.

Regardless of the method of treatment with monatomic oxygen, the reaction is confined to the surface. The modified region extends no more than 100 Å into the bulk material. Polymers containing C-H bonds react directly with monatomic oxygen to produce a variety of species, including ketones, aldehydes, alcohols and carboxylic acids, all bound on the surface. Silicone polymers form a surface layer of Si-OH groups.

This work was done by Glenn Spaulding and Steven L. Koontz of **Johnson Space Center**. *For further information, Circle 105 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center [see page 20]. Refer to MSC-21529

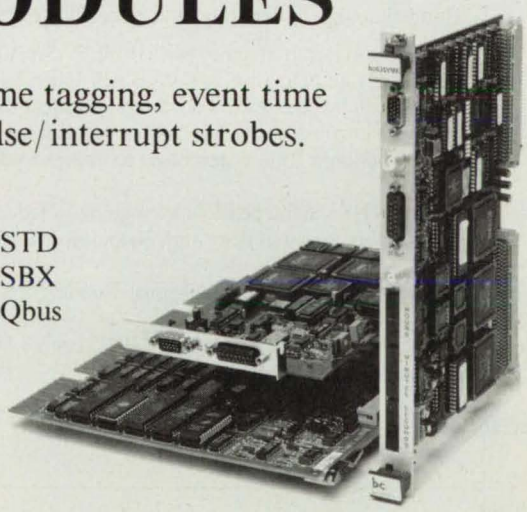


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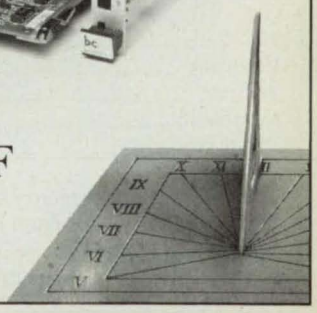
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Effects of Exercise During Bed Rest

Researchers seek regimens to preserve fitness during bed rest and in outer space.

A pair of reports adds to the growing body of knowledge of the physical deconditioning caused by prolonged bed rest and the effectiveness of various exercise regimens in preserving or restoring fitness. The major objective of research in this field is to determine what regimens to prescribe to astronauts before flight, during prolonged weightlessness, and immediately before returning to Earth. Presumably, this knowledge could also benefit patients confined by illness or injury.

The first report discusses an experiment on the effects of two types of periodic, intense, short-duration exercise during bed rest. This experiment is also discussed in the documents "Effects of Exercise During Prolonged Bed Rest" (ARC-12190), *NASA Tech Briefs*, Vol. 16, No. 9 (1992), page 90, and "Isotonic and Isokinetic Exercise During Bed Rest" (ARC-12180), *NASA Tech Briefs*, Vol. 17, No. 1 (1993), page 136. To recapitulate: the experiment involved 19 healthy middle-aged male volunteers who remained in bed for 30 days. Five of them constituted a control group that did not exercise, seven performed isotonic exercise (on a stationary electronic ergometer), and seven performed isokinetic leg exercise (on a computerized weight-lifting machine).

The isokinetic exercise preserved or even increased strength but not the capacity for work (that is, the capacity to sustain exercise at a given level). The isotonic exercise did not maintain strength but did maintain the capacity for work. These conclusions and other results of this experiment lead to the following additional conclusions concerning exercises for astronauts: It is likely that focused, short bouts of nearly peak exercise can be substituted for the many long hours of submaximal exercise training currently used. Because this type of protocol appeared to function well in maintaining aerobic power in both a previous ambulatory study and in this bed-rest study, there is no reason to assume it should not work equally well for astronauts in microgravity. Further study is needed to develop optimal protocols for maintenance of strength and endurance.

The second report reviews the knowledge acquired thus far, with a view toward the development of protocols for exercise regimens. It discusses the work required of astronauts inside and outside spacecraft, the effectiveness of exercise in terms of various quantitative measures of fitness, the strengths and endurances of muscles, calcium metabolism and the mineral contents of bones, and mood and psychological performance. The report concludes with tentative protocols for ground-based and in-flight exercise regimens for astronauts.

This work was done by John E. Greenleaf of **Ames Research Center** *and Edmund M. Bernauer of the University of California, Davis. To obtain copies of the reports, "Work capacity during 30 days of bed rest with isotonic and isokinetic exercise training" and "Exercise-training protocols for astronauts in microgravity," Circle 64 on the TSP Request Card.*
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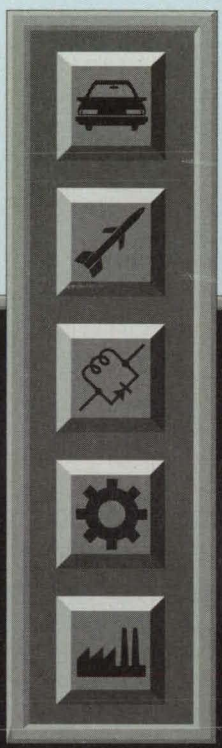
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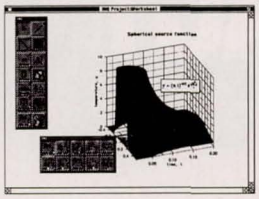
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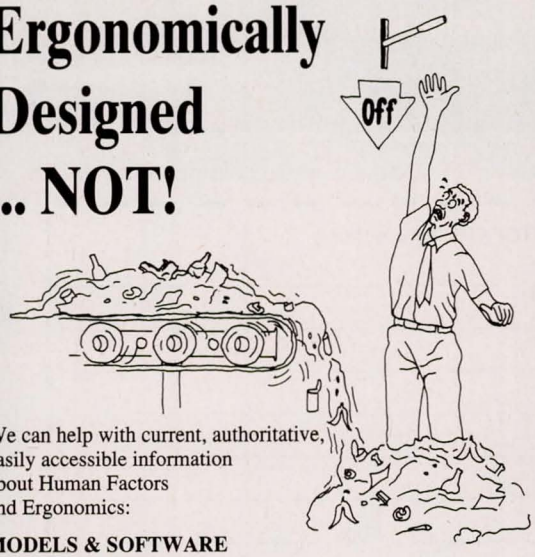
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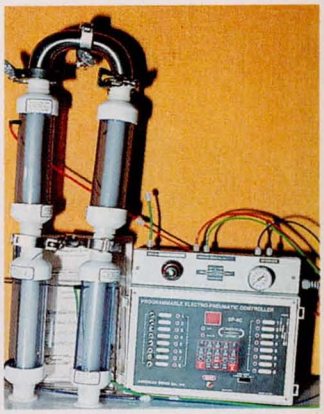
Cognition Corp., Billerica, MA, has released **computer-aided design software** that provides cost data for a product as it is designed. Cost Advantage™, an object-oriented expert system, uses rules-based logic to calculate the cost impact of design decisions and works with such solids modeling systems as Pro/Engineer®, I-DEAS™, and Mechanical Advantage™. A development toolkit helps users add their own cost rules.
For More Information Circle No. 778

Enterprise Communications & Computing Inc., San Diego, CA, has introduced the Multi-Protocol Connectivity Manager™ (MPCM), the first **front-end communications processor** to offer local-area network and asynchronous connectivity through a single SCSI bus port. Offered on NCR System 3000 computers and Sun SPARCservers, the MPCM facilitates communications among multi-protocol and multi-host networks, eliminating the need to have separate communications boards for each supported bus.
For More Information Circle No. 774



The HSV-1000 **high-speed video system** from NAC Visual Systems, Burbank, CA, offers 1000 high-resolution color pictures per second for engineering, manufacturing, and quality control applications. Data can be displayed on the monitor in real time, slow motion, stop frame, forward, or reverse, and can be printed. The portable HSV-1000 is a stand-alone workstation that incorporates a VCR, swivel monitor, and a handheld controller.
For More Information Circle No. 782

InSoft Inc., Mechanicsburg, PA, has released an update to Communique!™, **multimedia groupware** that enables simultaneous real-time video and multimedia conferences at multiple sites on a network without having to integrate T1 lines. Communique!'s compression ratios work with four- or seven-bit grayscale video using Sun's VideoPix® board over the lower volume lines. A similar version supports 24-bit full-motion color video on Parallax Graphics' XVideo® board.
For More Information Circle No. 780



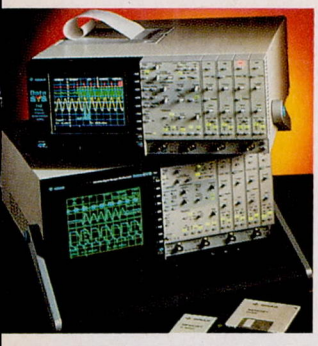
The first **peristaltic pump** free of valves or rotating parts has been introduced by American Dengi Co. Inc., Scotch Plains, NJ. The microprocessor-controlled device operates by sequentially collapsing the flexible tubular segments in the pumping channel. It can transfer liquids or semi-solids without clogging. Normal operating pressures range from 5 to 100 psi with pumping volumes from ml/day to gal/min.
For More Information Circle No. 786

Mosaic Industries Inc., Newark, CA, has announced the QED board, a 3.2" x 4" **embedded controller** that hosts a high-level programming environment in on-board ROM. A FORTH interactive compiler and 68HC11 assembler facilitate programming via any PC or terminal, and symbolic debugging tools support breakpoint insertion, tracing, and single stepping. The built-in programming toolkit includes a multitasking executive, memory manager, and I/O device drivers.
For More Information Circle No. 784

A portable **infrared thermometer** from Wahl Instruments Inc., Culver City, CA, automatically focuses on small targets. The model DHS-34A Heat Spy provides instant temperature measurement of targets as small as 0.35" from a distance of less than 20" and displays readings from -50 to 1000 °C.
For More Information Circle No. 798

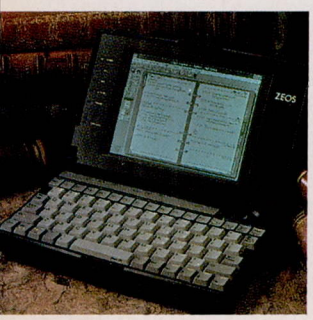
New on the Market

The DataSYS™ 700 line of multi-dimensional **measurement systems** from Gould Inc., Valley View, OH, extends the processing, display, and storage capabilities of digital storage oscilloscopes to provide complete waveform testing solutions. The instruments incorporate high-brightness color displays, integral disk drives, and built-in printers. Features include wide bandwidth (150 MHz on up to four channels), high sample rate (100 MS/s for 8-bit data on four channels), and long memory (50 KB per channel).
For More Information Circle No. 792



Kilovac Corp., Santa Barbara, CA, has introduced a highly-reliable 270 Vdc, 10A **power switching relay**. The new AP10A is rated from -55 to 85 °C and can be used for a wide range of 270 Vdc, 155 Vdc, and 120 Vdc applications. Measuring just 1.7 cubic inches, the lightweight AP10A provides more than 2000 volts of isolation across open contacts, can switch at up to 1000 Vdc at lower current without damage, and dissipates less than 3 watts at 10A.
For More Information Circle No. 794

The Contenda, an innovative **sub-notebook computer system** offering the features of a desktop workstation, has been announced by ZEOS International Ltd., Minneapolis, MN. Measuring 9.7" x 6.1" and weighing less than 4 pounds, the computer employs an Intel 386SL microprocessor running at 25 MHz and comes with an 80 MB hard disk drive, 2 MB of RAM, a 7.4" diagonal VGA backlit screen, and a built-in trackball.
For More Information Circle No. 788



Mykroy/Mycalex Ceramics, Clifton, NJ, has developed glass-bonded mica composites that act as **thermoplastic electrical and thermal insulators**, remaining dimensionally stable during continuous operation from cryogenic temperatures to 700 °C. Dubbed cermoplastics, the materials are machinable with conventional tools and offer tight tolerances, insert molding, and consistent part-to-part reproducibility.
For More Information Circle No. 776

Crystal Semiconductor Corp., Austin, TX, has produced two **single-chip audio coder/decoders (codecs)** for the emerging multimedia PC market. Both provide stereo 16-bit audio and are pin-compatible with Analog Devices' AD1848. Additionally, one enhances the basic AD1848 feature set to include 4-to-1 adaptive differential pulse code modulation compression/decompression.
For More Information Circle No. 790

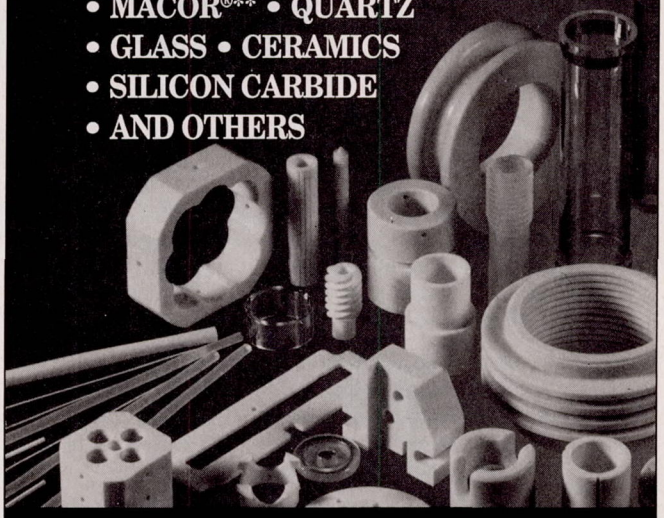


A highly-accurate **ultrasonic thickness gauge** from Magnetic Analysis Corp., Mount Vernon, NY, employs a pulse-echo technique similar to sonar. The single-channel TG-1 is designed for on-line applications requiring continuous thickness measurement as well as off-line applications that necessitate point-by-point measurements. It uses a square pulser suitable for transducers in the 0.5 to 20 MHz range and a receiver with matching bandwidth.
For More Information Circle No. 796

Instrument Technology Inc. (ITI), Westfield, MA, has unveiled a family of **articulating fiberscopes**. Available in 6 mm, 8 mm, and 11 mm sizes, they feature four-way articulation with single control for right or left hand operation; eight interchangeable heads offering four fields of view and two lines of sight; complete environmental protection, load control, and impact resistance; and a high-resolution image guide.
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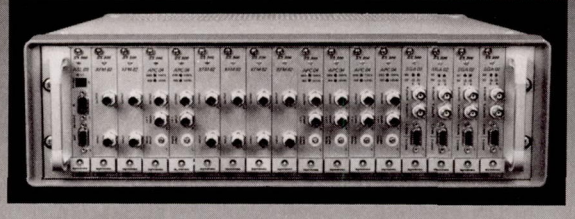
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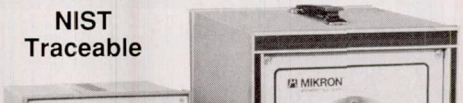
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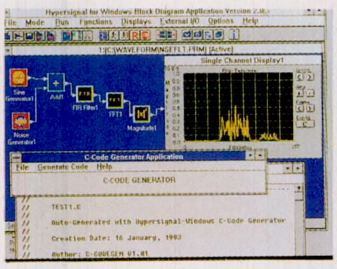
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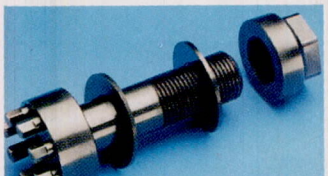
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New on the Market

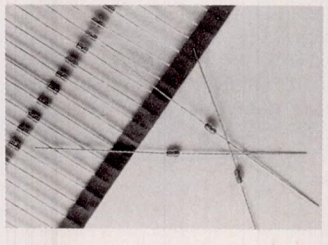


Hyperception Inc., Dallas, TX, has released a **C code generator** designed to work with Hypersignal-Windows Block Diagram, an object-oriented simulation program for signal processing. Programmers now can test algorithms in a visual environment and generate C code to run the algorithms outside the programs. Once the generator produces C code for the algorithm, it may be compiled with the DSP chip manufacturer's compiler to enable the program to run in real time on a processor.
For More Information Circle No. 770

Superbolt Inc., Carnegie, PA, has developed what it claims is the world's strongest **bolting system**--a 1", 12 tpi system, subjected repeatly to a 150,000-lb load, shows no signs of failure. The system comprises a multi-jackbolt tensioner called an Ultrabolt, two hardened washers, and a patented stress-equalizing nut, dubbed Flexnut. The components are made from AerMet 100, a new high-strength, fatigue-resistant alloy from Carpenter Technology.
For More Information Circle No. 772



Fenwal Electronics Inc., Milford, MA, has announced its NTC glass encapsulated Uni-Chip **thermistors** for highly-automated assembly operations. Available in bulk packages or on tape and reel, Uni-Chips feature resistance values of 1 K to 5 megohms, resistance tolerances of 1% to 10%, and 1 °C accuracy from 0 to 100 °C.
For More Information Circle No. 760



Dynamic Soft Analysis Inc., Pittsburgh, PA, has released BETAsoft-B Basic, **thermal analysis software** for electronic boards. Priced at $1245, the DOS-based, Windows-compatible program offers high accuracy (±3 °C) and speed (3 minutes on 386SX 16 MHz for 100 components), and can be used with more sophisticated BETAsoft platforms. To conserve time, users can employ an interface to import board design data available to most CAD systems.
For More Information Circle No. 762

Finger-Mouse, a **membrane pad** designed by Automated Control Concepts Inc., Neptune, NJ, translates finger motion directly into cursor motion. Fast finger movements on the pad move the cursor rapidly, while slower movements provide finer control. The Windows-compatible pad can be integrated into any mouse-based application and is provided with ACC's NEMA 4/12 OP/STATION™, a prepackaged industrial workstation designed for use in harsh environments.
For More Information Circle No. 768



A series of single-output **DC/DC converters** from CALEX Mfg. Co. Inc., Concord, CA, provides 25-30 watts of output power in a 2.02" x 1.62" x 0.55" package. Ideal for telecommunications applications, they are the first DC/DC converters to provide 17 watts of power per cubic inch in this package size. The units have transient overvoltage suppressor diode protection at the output terminals and feature overcurrent and overtemperature protection.
For More Information Circle No. 766

Giddings & Lewis, Fond du Lac, WI, has introduced the PiC900™ Turbo², a line of **programmable industrial computers** utilizing Intel 80486SX/DX microprocessors. The computers combine high-speed information sensing, logic, and process control with ease of programming, networking, and a data base—all in a single control package. A 25 MHz configuration with a math coprocessor and a 16 MHz model without the coprocessor are available.
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Entry-level engineer with double MS in artificial intelligence, robotics, shape and speech recognition and BS in EE and linear/nonlinear control. Internship in fuzzy logic, experience with AutoCAD. Languages: Assembler (8086), Pascal, C, LISP, PROLOG. Fluent in English and French plus nine years of German. Willing to travel and relocate.
Box number 43A

Available immediately. 25 years experience in electrical and electronic applications; potting, encapsulation, embedding, conformal coating, paints, and marking inks; thermosets and thermoplastics. Experience with ESD, RFI/EMI shielding, conductive, thermally conductive materials and all phases of plastics and polymer processing. Excellent writing skills, specifications, reports; customer/vendor interface skills; supervisory experience. MS in polymer engineering.
Box number 44A

Ph.D in electrical engineering with over 20 years industrial research experience. Interested in a supervisory position in the development of advanced microwave communications systems. Have designed microwave/millimeter wave components and receiving systems using CAD tools. Fifteen published papers and one patent award in above areas.
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Software architect: 25+ years. Excel in design, development, and implementation of large-scale real-time, embedded, distributed, concurrent, and parallel processing projects. Skilled in use of computer languages, operating systems, communications, and hardware. Michael Andrescavage. Tel. 215-286-2053.
Box number 46A

Quality/major subcontracts. 27 years experience on technical programs in quality assurance, quality control, major subcontracts, and procurement. Mil-Std-2000 certified. Other experience in operations management, standards engineering, safety, building, ISO-9000, and configuration management. BA in math/physics. Will relocate.
Box number 47A

MSME/MBA shirt sleeve leader. Experienced in all areas of manufacturing and planning, facilities, and project engineering. 20 years defining problems and finding solutions. Turned two engineering groups into high profit centers. Computer literate including AutoCAD.
Box number 48A

Test engineer/QC/QAE, process development, design, BSEE, MBA in management. 25 years of design, analysis, manufacturing, tooling, quality assurance, procurement experience within defense industries. Recognized for ability to improve production and quality.
Box number 49A

Senior software engineer/technical manager (BS in math, MSME) with over 20 years experience in software design/development. Specialist in porting, conversion, optimization, and parallelization. Demonstrated ability to deliver projects on time with exceptional people-handling skills. Looking for full-time contract or permanent employment. US citizen willing to travel and relocate.
Box number 50A

Ph.D in materials science (May 1993) with experience in a new plasma-based ion implantation technology, materials characterization techniques, tribological, and corrosion testing. Interested in research position in the surface modification of materials or plasma processing fields. Willing to relocate. US citizen.
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Box number 52A

To submit an ad for inclusion in this column, send a copy of your resume and a 50-word summary to: *NASA Tech Briefs*, 41 East 42nd St., New York, NY 10017, ATTN: Gregg McQueen.

To Request Resumes:

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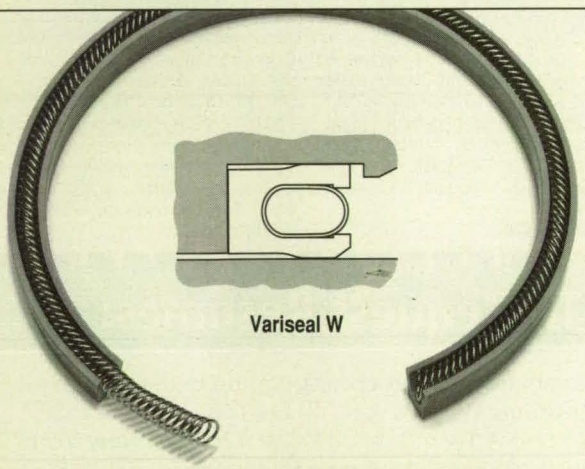
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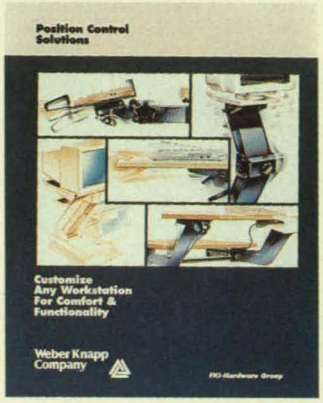
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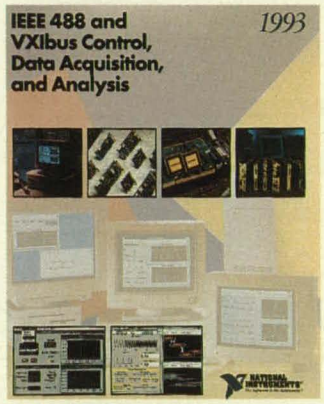
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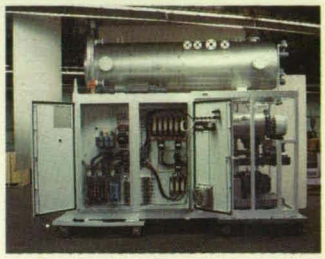
Weber Knapp Co., Jamestown, NY, has published a brochure describing **computer furniture and workstation accessories** that permit work surface adjustment to prevent repetitive motion injuries. Featured products include computer monitor height adjustment and keyboard positioning devices, a unique computer mouse/trackball for workstations, and a heavy-duty positioning mechanism for large work surfaces. Travel ranges, tilt angles, and weight capacities are listed.
For More Information Circle No. 702



VXIbus hardware and software controller products are showcased in a brochure from National Instruments, Austin, TX. It explains the benefits of VXI-based instrumentation and how to control VXI systems with GPIB-equipped computers, embedded controllers, and MXIbus-equipped computers. Featured products include GPIB-VXI/C and MXIbus-based interface kits and a line of VXIpc-486™ embedded computers.
For More Information Circle No. 710

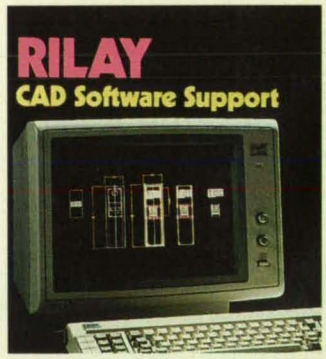
A guide to selecting **uninterruptible power systems** is available from Computer Power Inc., High Bridge, NJ. It is designed to help users sort through the characteristics of UPS and related power protection products to choose the appropriate system for critical industrial, medical, and military applications.
For More Information Circle No. 712

INDEECO, St. Louis, MO, has released a catalog of its custom-designed **vaporizers and fluid heat transfer systems**, which provide precise temperature control of heat transfer oils or fluids circulated through any closed loop process. Packaged systems include electric heaters, pumps, valves, gauges, expansion tanks, temperature and power controls, heat exchangers, and all necessary plumbing.
For More Information Circle No. 708



An updated catalog and reference guide from Keithley Instruments Inc., Cleveland, OH, includes technical data, specifications, selection guides, and application information on the company's broad line of **test instruments and accessories**. New products include the model 2001 7½-digit DMM, 80-channel and 400-channel switch systems, several switching cards, an LCZ meter, and two parametric test systems.
For More Information Circle No. 714

A **conductive thermoplastics** brochure from RTP Co., Winona, MN, serves as a primer and reference on the uses of conductive materials. It reviews the phenomenon of static electricity and provides current information on industry standards. Included is a sheet-extruded sample of PermaStat™ 600 to demonstrate color brightness and surface resistivity.
For More Information Circle No. 706



A 16-page booklet from Rittal Corp., Springfield, OH, illustrates its **enclosure design software**. The Rilay, Power Plan, and Therm programs calculate enclosure requirements based on customer specifications for easy ordering.
For More Information Circle No. 704

New Literature

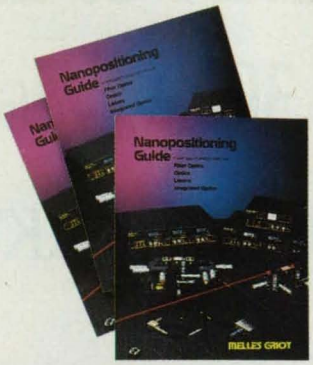
ZEM Press, Bethesda, MD, has published the third edition of the *CAD Rating Guide*, which details 105 **CAD programs** for mechanical design, mapping, 3D modeling, structural analysis, and NC tooling, with emphasis on geographic information systems, finite element modeling, and animation systems. The guide offers 505 pages of background information, vendor and product data, and user comments.
For More Information Circle No. 728

TA Instruments Inc., New Castle, DE, is offering literature on Modulated DSC™ technology, a novel **thermal analysis** technique that provides insights into the structure and behavior of materials unavailable using conventional DSC methods. It offers improved resolution and sensitivity, direct heat capacity measurement, and separation of reversing and nonreversing characteristics of thermal events.
For More Information Circle No. 718



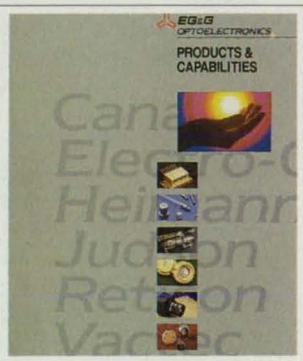
The 1993 Plastics DIGEST from International Plastics Selector, Englewood, CA, details more than 15,500 **plastics, thermoplastics, and thermosets**. A new Underwriters Laboratories (UL) test description section includes summaries of UL tests 94 and 746A pertaining to flammability and ignition properties. A directory of plastics industry organizations also is provided.
For More Information Circle No. 722

Technological advances in the **machine vision** industry will be closely aligned to the development of **high definition television** (HDTV), predicts a technical report published by the Machine Vision Association of the Society of Manufacturing Engineers. Entitled *HDTV: Applications in Manufacturing*, it outlines such benefits as improved measurement capabilities and development of decentralized digital imagers on shop floors that link information via optical fibers to a central computer.
For More Information Circle No. 716



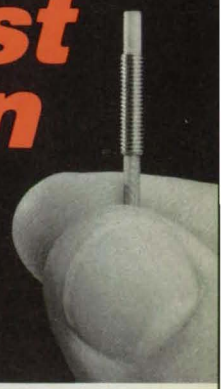
A 115-page **nanopositioning** guide released by Melles Griot, Irvine, CA, describes submicron positioning technology and details a wide range of positioning equipment for fiber optics, integrated optics, laser, and other optical applications. The new equipment uses frictionless flexure technology and rigid athermalized designs to provide ultra-high-resolution and stability.
For More Information Circle No. 726

A four-color brochure presents **flexible circuits** from Hughes Interconnect Systems Division, Irvine, CA, designed to solve high-speed, high-density packaging and interconnect problems. They include single- and double-sided, multilayer, rigid-flex, fine-line, power-flex, and cryogenic circuits. Showcased are the new Gold Dot™ products, which integrate high-density interconnects into flexible circuit assemblies.
For More Information Circle No. 724



EG&G Optoelectronics, Sunnyvale, CA, has issued a 16-page **electro-optics products and capabilities** brochure. The company's six divisions—EG&G Canada, Electro-Optics, Heimann Optoelectronics, Judson, Reticon, and Vactec—offer products ranging from the UV to the far infrared, from simple emitters, flashlamps, and photocells to more sophisticated semiconductor lasers, detectors, and imaging devices. Featured products include silicon and InGaAs avalanche photodiodes, PID lamps, trigger coils, and pyro-IR detectors.
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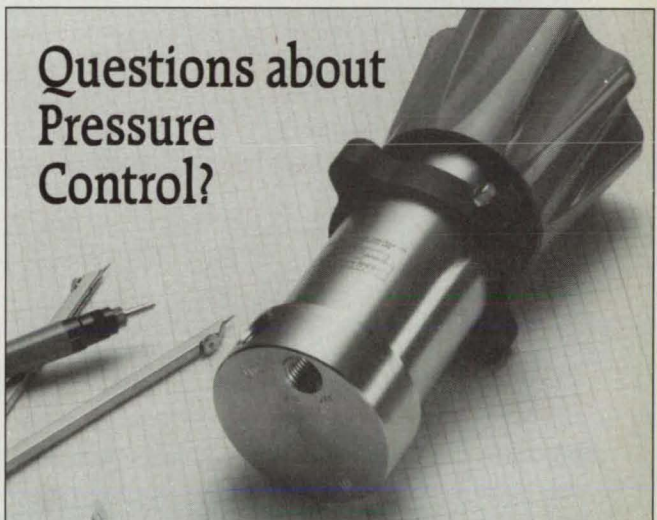
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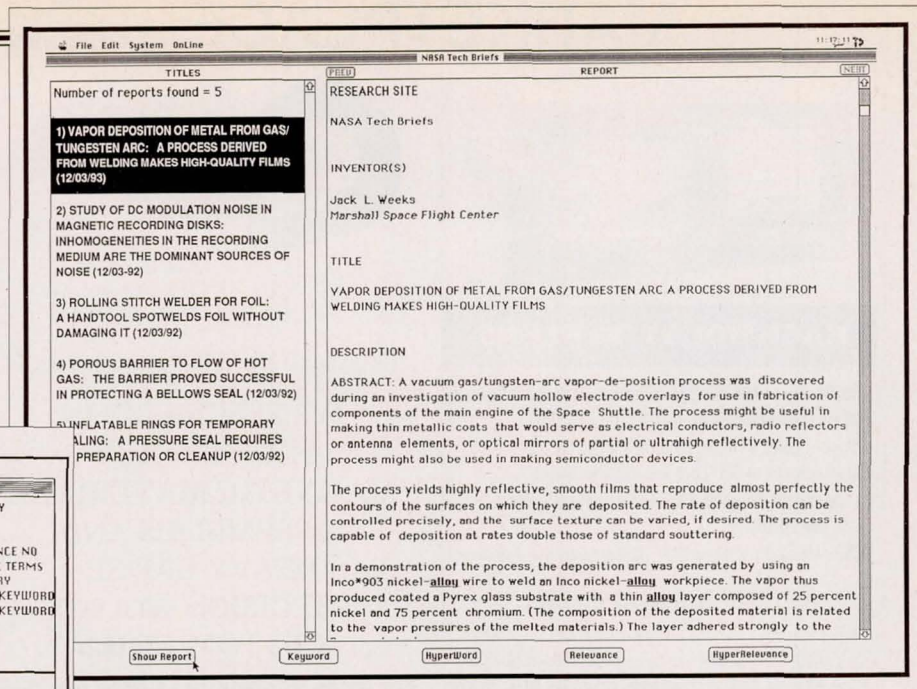
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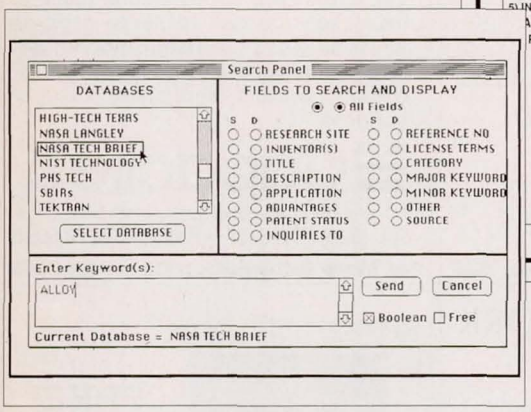
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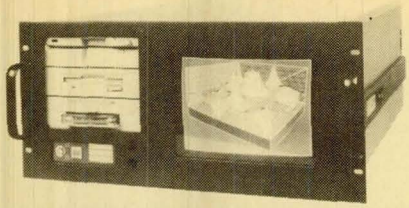
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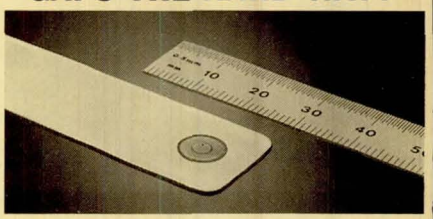
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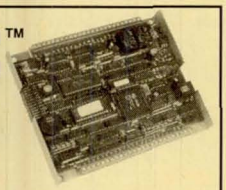
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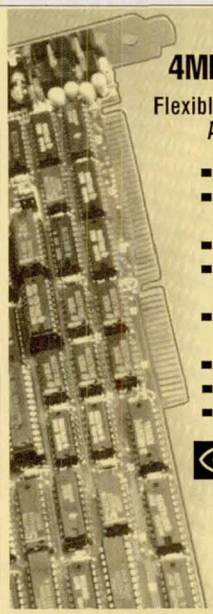
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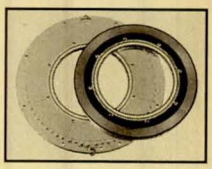
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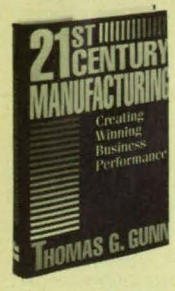
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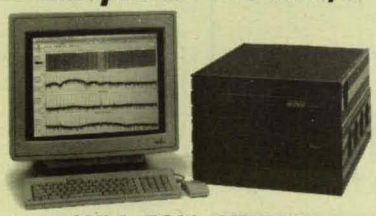
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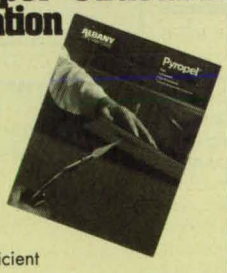
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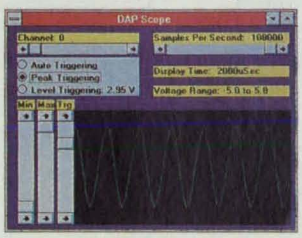
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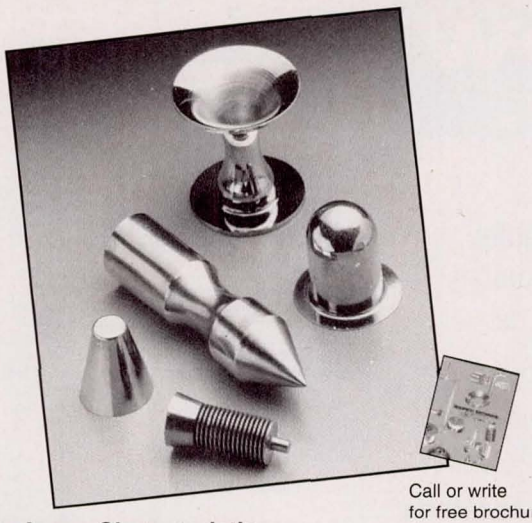
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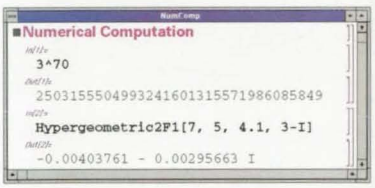
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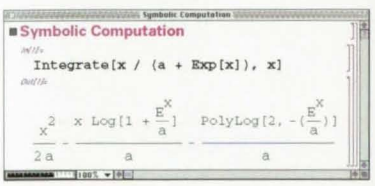
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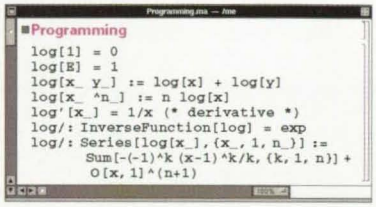


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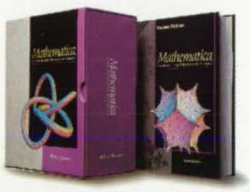
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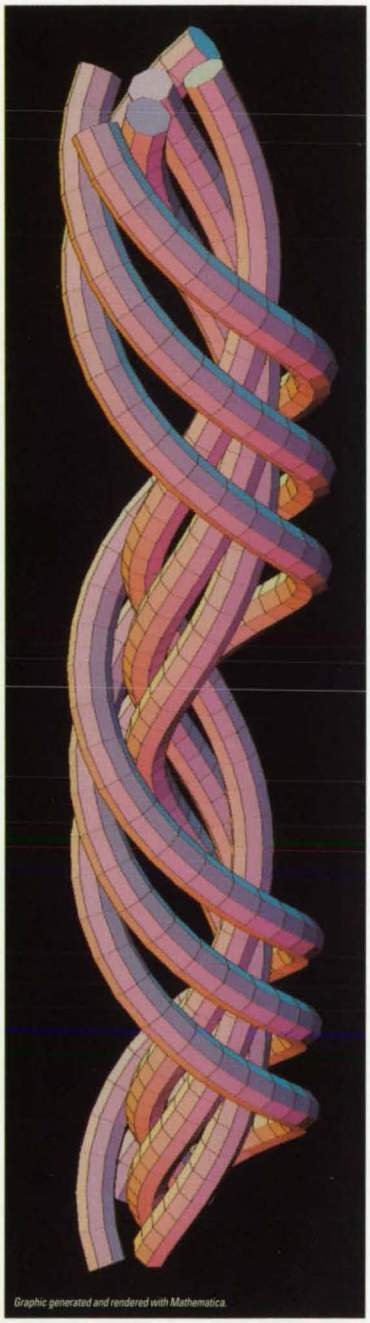
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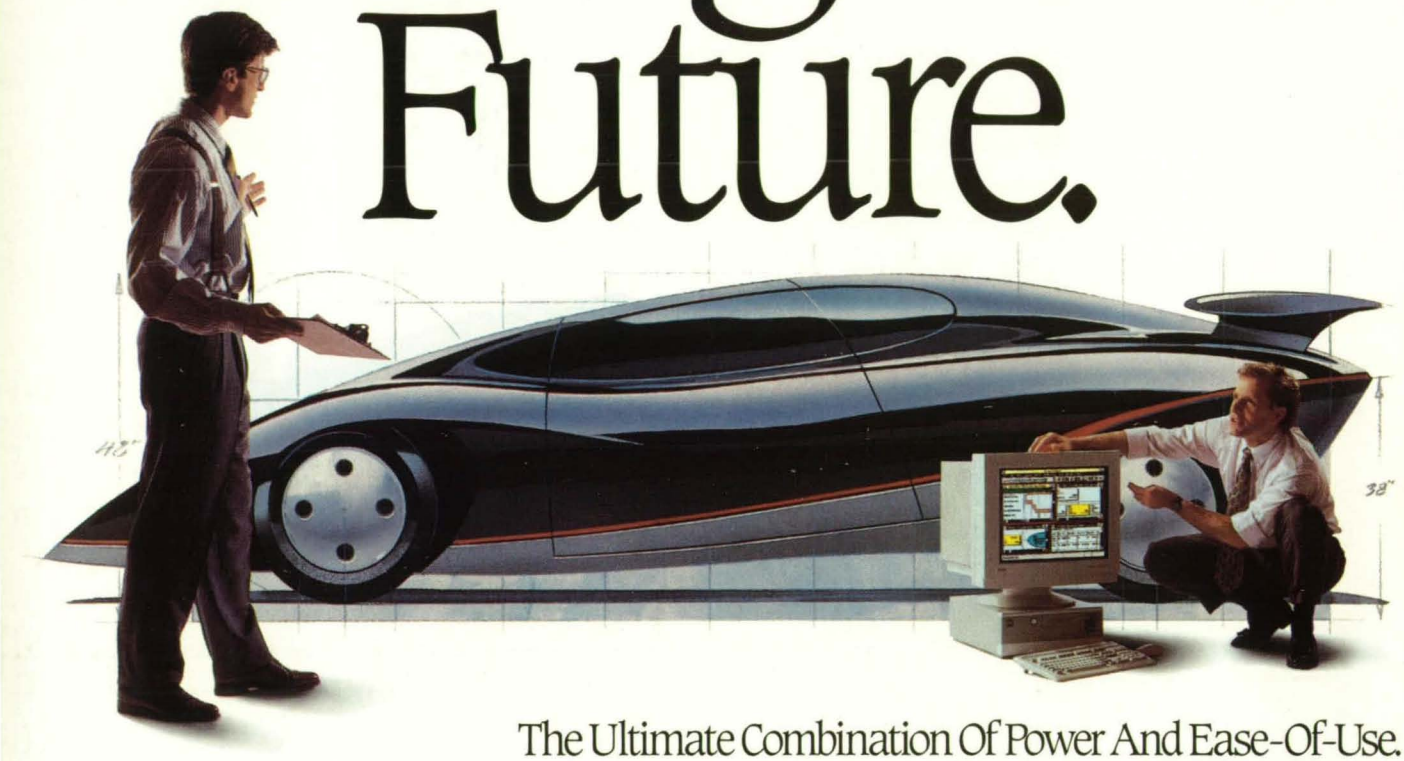
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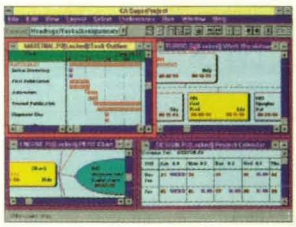
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